Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band	ET Docket No. 13-49

REPLY COMMENTS OF THE NATIONAL CABLE & TELECOMMUNICATIONS ASSOCIATION

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I. INTRODUCTION AND SUMMARY.

The record in this proceeding confirms the Commission's finding that there is an unlicensed spectrum shortage.[1] A wide variety of commenters detail the importance of unlicensed technologies to the national economy, innovative uses of Wi-Fi, and usage trends that predict that unlicensed networks will soon be the single most heavily used consumer connection to the Internet. These commenters also demonstrate, however, that existing unlicensed spectrum resources are straining under this pressure, and will not support near-term consumer demand. It is clear that the Commission must take action now to ensure that the country has the unlicensed spectrum it needs in the 5 GHz band to support a continuation of the Wi-Fi success story – and that if the Commission does not designate additional unlicensed spectrum in this band, consumers will pay a heavy price.

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[1] *See Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, ET Docket No. 13-49, Notice of Proposed Rulemaking, 28 FCC Rcd 1769, 1773 ¶ 11 (2013) (*NPRM*).

The process of making spectrum available for wireless broadband in the current environment, however, presents the Commission with difficult choices. This is the case because there is simply no more "greenfield" spectrum available for licensed or unlicensed wireless broadband use that does not contain incumbent operations. Today's spectrum policy process, therefore, requires the Commission to address the spectrum shortage by either relocating incumbent operations or finding ways to allow sharing.

Both of these options create real costs. But maintaining the status quo in the face of radical changes in technology and the marketplace is even more costly. Many current uses of spectrum are substantially less efficient and productive compared with modern wireless broadband uses like Wi-Fi. And many of these incumbents gained spectrum rights under now-disfavored assignment mechanisms that, unlike auctions or unlicensed designations, do not create incentives or requirements for intensive or efficient use. So, in light of current spectrum scarcity, precluding widespread consumer use of valuable bands in order to over-protect operations that use spectrum inefficiently, serve a small number of consumers, or have failed to use a band intensively after many years, does not serve the public interest. Such inaction would put the country on an unsustainable spectrum policy path.

Recognizing that failure to address the nation's exploding demand for wireless broadband is unacceptable, Congress, the Administration, and the Commission have begun a process of identifying candidate bands for incumbent relocation or sharing where the benefits of such action outweigh the costs – and have correctly singled out the 5 GHz band for sharing. Most recently, President Obama issued a Presidential Memorandum specifically stating that allowing additional unlicensed operation in the 5 GHz band is important to national economic policy.

Additional Wi-Fi-usable 5 GHz spectrum will also be critical to the President's new ConnectED initiative, which within five years intends to provide 99 percent of America's students with next-generation gigabit broadband and high-speed wireless in their schools and libraries.[2] The new IEEE 802.11ac standard for Wi-Fi will be critical to the President's goal of delivering up-to-gigabit speeds to students in our nation's schools to enable digital learning.[3] This is the case because even if the program deploys a high-speed fiber connection to every school, only 802.11ac Wi-Fi can currently distribute gigabit connectivity wirelessly across the entire school premises, including outdoor study areas, throughout the school building, into classrooms and libraries, and to each individual student wherever he or she may be. As described in more detail below, the 802.11ac standard is designed only for the 5 GHz band, and full implementation of the standard will require access to additional 5 GHz spectrum to accommodate the wide channels necessary for gigabit connectivity. Moreover, the education community has recognized that in order for digital curricula to reach their full potential, students must have access to digital information and educational systems not only at school, but in the home. Widespread access to 802.11ac-based Wi-Fi both in schools and in homes across the nation will also help to ensure that students reap the full benefits of the President's ConnectED initiative.

To be sure, there is hard work to be done to enable sharing in the 5 GHz band. As the record in this proceeding confirms, however, achieving the President's and the Commission's

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[2] The White House, *ConnectED: President Obama's Plan for Connecting All Schools to the Digital Age*, *available at* http://www.whitehouse.gov/sites/default/files/docs/connected_fact_sheet.pdf (last visited July 12, 2013).

[3] *See NPRM*, 28 FCC Rcd at 1775 ¶ 18 ("The new 802.11ac standard would allow for a significant increase in bandwidth and data rates in the 5 GHz band–it specifies bandwidths of 20, 40, 80, and 160 megahertz with a link data rate of approximately 1 Gbit/s.").

goals in the 5 GHz band will be far easier than in any other candidate band – making it the best chance the Commission has to address the unlicensed spectrum shortage.[4] This is the case because (1) extending current unlicensed operations in the 5 GHz band will be less costly than establishing a brand new unlicensed band in other portions of the radio spectrum, (2) the 5 GHz band is the only band in the United States that could support the next-generation 802.11ac "gigabit Wi-Fi" standard, and (3) incumbent use of the 5 GHz band is more conducive to sharing than any other potential band.

In the U-NII-1 band,[5] for example, only one incumbent company occupies this 100 megahertz band. Although the Commission believed a decade ago that a large group of companies would use this band intensively, the reality is now clearly otherwise. Globalstar alone occupies the entire band today, and uses it for only four feeder link locations in the entire country, supporting a specialized product serving a limited U.S. customer base. Furthermore, Globalstar already shares this band with unlicensed devices.[6] U-NII-1 therefore is a perfect place for the Commission to make technical rule changes that will allow effective sharing and efficient band use.

Similarly, the U-NII-4 band is an excellent candidate for sharing compared with other possible bands.[7] Here, the Commission allowed Intelligent Transportation Systems (ITS)

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[4] The 600 MHz and 3.5 GHz bands will also play an important role in addressing the unlicensed spectrum shortage, as both have the potential to provide additional unlicensed spectrum with favorable propagation characteristics.

[5] The U-NII-1 portion of the 5 GHz band is located between 5.15 and 5.25 GHz. *NPRM*, 28 FCC Rcd at 1770-71 ¶ 4.

[6] *See NPRM*, 28 FCC Rcd at 1780-81 ¶ 36 (noting that Globalstar and U-NII devices are both authorized to operate in U-NII-1).

[7] The U-NII-4 portion of the 5 GHz band is located between 5.85 and 5.925 GHz. *Id.* at 1773 ¶ 13.

licensees to share 75 megahertz with satellite and government users nearly fifteen years ago. But despite the reservation of an enormous spectrum block for its use (in addition to other spectrum available for ITS in the 900 MHz band[8]), ITS has yet to deploy even one commercial system in this band. Furthermore, the satellite licensees in this band use it "lightly"[9] and have already demonstrated their ability to share the band by devising a sharing arrangement with ITS. While ITS and satellite operations are important, finding a band without a large deployed user base, without intensive operations, and where sharing is already demonstrated to work, is exceedingly rare. Furthermore, because ITS licensees are still in the testing phase for their technology, they are in a far better position to incorporate sharing into system designs than would be licensees in bands with deployed users.

In sum, the Commission should move expeditiously to enable sharing in U-NII-1 and U-NII-4 because it simply will not find any other bands where sharing fits as well and that will produce such enormous public benefits.[10] To achieve this goal, NCTA therefore requests that the Commission enact its proposals to: (1) adopt rule changes for U-NII-1 that permit outdoor operation and a higher transmit power limit; and (2) designate U-NII-4 for unlicensed use with technical rules matching those that apply to U-NII-3.[11] NCTA also requests that the Commission enact its proposal to add 25 megahertz to U-NII-3 and adopt technical rule changes for that band that will continue to permit the operation of point-to-point wireless backhaul links.

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[8] 47 C.F.R. § 90.353.

[9] *NPRM*, 28 FCC Rcd at 1797 ¶ 90.

[10] NCTA recognizes that, depending on the technical parameters adopted, the new U-NII-2B band may also provide additional useful unlicensed spectrum. NCTA also recognizes, however, that sharing in the U-NII-2B band may require additional study. *See id.* at 1773 ¶ 12 (defining the U-NII-2B band as located between 5.35 and 5.47 GHz).

[11] The U-NII-3 portion of the 5 GHz band is located between 5.725 and 5.825 GHz. *Id.* at 1770-71 ¶ 4.

These changes will greatly improve the nation's access to wireless broadband spectrum by converting currently underutilized bands into well-utilized bands that protect incumbent users and also support exploding consumer Wi-Fi demand.

II. THE RECORD ESTABLISHES THE PRESSING NEED BOTH TO DESIGNATE NEW 5 GHZ BANDS FOR UNLICENSED TECHNOLOGIES AND TO UPDATE U-NII TECHNICAL RULES.

The record in this proceeding overwhelmingly confirms the benefits that innovative unlicensed broadband services such as Wi-Fi provide to consumers and the U.S. economy. NCTA agrees with the Wi-Fi Alliance that "Wi-Fi technology has been an unqualified success and a driving force in the U.S. economy," and that "the use of Wi-Fi technology in a variety of sectors has improved American businesses."[12] The Information Technology Industry Council similarly observes that "Wi-Fi currently offers a variety of benefits to consumers, including ubiquitous, nomadic Internet access in homes and retail establishments, and is increasingly being used for cellular offloading."[13] Cisco states that "Wi-Fi has been one of the great American success stories, spurring innovation, job creation, economic growth, and bringing incredible new opportunities to businesses and consumers."[14] Shared Spectrum Company notes that "[m]illions of Americans look to Wi-Fi for home and office coverage for their daily internet use,"[15] and Qualcomm highlights "the positive impact that Wi-Fi has had on so many facets of American life."[16] Similarly, Google and Microsoft note that "Wi-Fi is the most heavily used method of

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[12] Comments of Wi-Fi Alliance at 2 (Wi-Fi Alliance Comments). Unless otherwise noted, all comment citations herein are to comments filed on May 28, 2013 in ET Docket No. 13-49.

[13] Comments of the Information Technology Industry Council at 3 (ITIC Comments).

[14] Comments of Cisco Systems, Inc. at 1-2 (Cisco Comments).

[15] Comments of Shared Spectrum Company at 3 (SSC Comments).

[16] Comments of Qualcomm Incorporated at ii (Qualcomm Comments).

wireless broadband connectivity."[17] Furthermore, Motorola Mobility explains that additional unlicensed spectrum could "alleviat[e] congestion from the commercial mobile broadband networks."[18]

Commenters also highlight the tremendous growth of Wi-Fi network investment and consumer demand. For example, Cablevision cites its growing Optimum Wi-Fi network, which has been used by over one million customers and which provided critical communications during Hurricane Sandy.[19] Time Warner Cable notes that the number of unique users accessing its cable Wi-Fi network grew by over 720 percent in December 2012 as compared to December 2011, and also mentions the important role its Wi-Fi network played in providing communications after Hurricane Sandy.[20] Comcast observes that the unique users of its Xfinity Wi-Fi network increased by 110 percent in 2012, and that in the last twelve months, the network "experienced triple-digit growth in both unique users and 'tonnage' (measured in GBs of traffic)."[21] Comcast also states that its Wi-Fi network helped family and friends to communicate in the wake of emergencies like Hurricane Sandy and the Boston Marathon bombing.[22] Shared Spectrum Company likewise notes the success of cable Wi-Fi networks as a service to American

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[17] Comments of Google Inc. and Microsoft Corporation at 3 (Google and Microsoft Comments).

[18] Comments of Motorola Mobility at 9 (Motorola Mobility Comments).

[19] Comments of Cablevision Systems Corporation at 2-3 (Cablevision Comments).

[20] Comments of Time Warner Cable Inc. at 5-6 (TWC Comments).

[21] Comments of Comcast Corporation at 8 (Comcast Comments).

[22] *Id.* at 13-14 (noting that Wi-Fi offers advantages over licensed technologies during emergencies as a result of "carrier-agnostic interoperability between end-user devices and network infrastructure" and "the natural resilience of a distributed, small-cell architecture" along with "the pervasiveness of the wired broadband networks that connect Wi-Fi access points to the Internet").

consumers and as a way to ease congestion on cellular networks.[23] Furthermore, Cisco emphasizes the proliferation of public Wi-Fi hotspots and the utility of Wi-Fi networks in times of crisis, highlighting the use of Comcast's cable Wi-Fi network in the aftermath of the Boston Marathon bombing.[24] Even in the short time since NCTA filed its initial comments in this proceeding, a variety of cable operators have continued to expand and enhance their Wi-Fi deployments.[25]

Commenters also agree, however, that in order for Wi-Fi to continue to be a successful driver of the American economy, the Commission must provide access to more usable spectrum in the 5 GHz band. Motorola Mobility calls the need for additional broadband spectrum "pressing"[26]; Google and Microsoft warn that "the 5 GHz bands currently available for unlicensed technologies will not be able to support growing consumer demand."[27] CEA refers to

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[23] SSC Comments at 3.

[24] Cisco Comments at 16-17.

[25] *Time Warner Cable Expands TWC WiFi™ Network into New York City*, TIME WARNER CABLE (July 11, 2013), http://www.timewarnercable.com/en/about-us/press/twc_expands_wifi_network_into_NYC0.html; Jeff Simmermon, *Time Warner Cable Making its NYC WiFi HotSpots Free to Anyone Until July 16th*, TWC UNTANGLED (July 11, 2013), http://www.twcableuntangled.com/2013/07/time-warner-cable-making-its-nyc-wifi-hotspots-free-to-anyone-until-july-16th/; *New York City, Cablevision, and Time Warner Cable Launch Public WiFi in 32 Parks Across the Five Boroughs*, FIERCECABLE (July 16, 2013), http://www.fiercecable.com/press-releases/new-york-city-cablevision-and-time-warner-cable-launch-public-wifi-32-parks; Roger Cheng, *Time Warner Cable, Cablevision Light up NYC Parks with Wi-Fi*, CNET (July 16, 2013), http://news.cnet.com/8301-1035_3-7593964-94/time-warner-cable-cablevision-light-up-nyc-parks-with-wi-fi/; *Christie Administration Partners with Cablevision to Offer Wi-Fi Access for NJ Transit Customers*, NJ TRANSIT (June 12, 2013), http://www.njtransit.com/tm/tm_servlet.srv?hdnPageAction=PressReleaseTo&PRESS_RELEASE_ID=2871; *Cox Business Hospitality WiFi to Launch Across National Footprint*, PR NEWSWIRE (June 25, 2013), http://www.prnewswire.com/news-releases/cox-business-hospitality-wifi-to-launch-across-national-footprint-212917171.html.

[26] Motorola Mobility Comments at 1.

[27] Google and Microsoft Comments at 4; *see id.* at 5 (noting the "growing exhaustion of 2.4 GHz spectrum").

the spectrum crunch as "a major national challenge."[28] Many commenters cite increased consumer demand for Wi-Fi[29] and the accompanying exhaustion of existing Wi-Fi spectrum in the 2.4 GHz band.[30] Even Globalstar recognized "consumers' ever-increasing desire for more data-intensive applications" and the existence of a "Wi-Fi Traffic Jam."[31]

Commenters also recognize the benefits of the IEEE 802.11ac standard, which can enable gigabit Wi-Fi,[32] but note that the benefits of IEEE 802.11ac will only be fully realized if the Commission frees more spectrum for Wi-Fi in the 5 GHz band.[33] Cisco notes that 802.11ac, "which is a 5 GHz band-only technology, can deliver much faster speeds and more efficient use than its predecessors."[34] Google and Microsoft predict that "[i]nnovators will use this standard to improve short-range video streaming and two-way, real-time video delivery, as well as other

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[28] Comments of the Consumer Electronics Association at 4 (CEA Comments).

[29] Cisco Comments at 6; CEA Comments at 4; Comcast Comments at 1; Comments of Globalstar, Inc. at 3 (Globalstar Comments); Comments of IEEE 802 at 9 (IEEE Comments).

[30] Cablevision Comments at 3; Cisco Comments at 6; Comcast Comments at 1; Google and Microsoft Comments at 5; Letter from Steve Martin, Senior Vice President of Engineering, Ruckus Wireless, Inc. to Rashmi Doshi, Chief, Laboratory Division, Office of Engineering and Technology, Federal Communications Commission at 1 (filed May 28, 2013); TWC Comments at 2.

[31] Globalstar Comments at 3.

[32] Cablevision Comments at 4-5; CEA Comments at 13; Cisco Comments at 17-19; Comcast Comments at 1; Google and Microsoft Comments at 4; IEEE Comments at 11; ITIC Comments at 4-5; Motorola Mobility Comments at 2-3; TWC Comments at 7; Wi-Fi Alliance Comments at 5-6.

[33] Cablevision Comments at 4-5; CEA Comments at 2-3; Cisco Comments at 19; Comcast Comments at 3; Google and Microsoft Comments at 4; IEEE Comments at 2, 27-28; ITIC Comments at 5; Motorola Mobility Comments at 2-3; Comments of Motorola Solutions, Inc. at 8-9 (Motorola Solutions Comments); TWC Comments at 7; Wi-Fi Alliance Comments at 6.

[34] Cisco Comments at 17.

high-bandwidth consumer applications."[35] While in theory 802.11ac technology could also be applied in the 2.4 GHz band, doing so would not permit users to reap the full benefits of the new standard. The 802.11ac standard relies on wide 80- and 160-megahertz channels to deliver increased throughput. Those wide channels simply are not available in the 2.4 GHz band. Moreover, while U-NII-3 spectrum has favorable technical rules for Wi-Fi, U-NII-3 is only 100 megahertz wide, meaning it can provide only one 80-megahertz 802.11ac channel and no contiguous 160-megahertz channels. Accordingly, more 5 GHz spectrum is needed to fully implement 802.11ac.

Commenters correctly argue that the 5 GHz band is the ideal band in which to address the unlicensed spectrum shortage.[36] Recognizing the unique advantages of the 5 GHz band, Motorola Mobility calls it "an ideal target for expanded unlicensed use."[37] The record is clear that only the 5 GHz band currently has the potential to offer unlicensed channels large enough to accommodate 160-megahertz 802.11ac "gigabit Wi-Fi" channels.[38] Cisco, for example, refers to 802.11ac as "5 GHz band-only technology."[39]

Moreover, many 5 GHz incumbents have not yet built out systems, meaning that these entities can more easily develop parameters for sharing the 5 GHz band than can incumbents in

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[35] Google and Microsoft Comments at 4; *see also* Motorola Solutions Comments at 2 ("Expanding access to additional portions of the 5 GHz band under rules harmonized with the 5 GHz bands already available for unlicensed operation would open up a variety of new services and applications, particularly as new technologies based on IEEE 802.11ac are developed.").

[36] Cisco Comments at 6; Comcast Comments at 2-3; Motorola Mobility Comments at 1; TWC Comments at 7.

[37] Motorola Mobility Comments at 1.

[38] Comcast Comments at 2; Comments of the National Cable & Telecommunications Association at 1 (NCTA Comments).

[39] Cisco Comments at 17.

other bands.[40] The 5 GHz band also has a "strong existing equipment ecosystem" of Wi-Fi-capable devices that already operate in the band.[41] Additional equipment has recently entered the marketplace that is designed specifically to support the new 802.11ac standard.[42] Finally, commenters note that the 5 GHz band benefits from extensive international harmonization, which permits equipment manufacturers to leverage economies of scale and scope.[43]

In short, the record in this proceeding confirms that the 5 GHz band is critical to the continued success of Wi-Fi and that the Commission must rapidly make more 5 GHz spectrum available for unlicensed use under technical rules that enable robust Wi-Fi operations in order to support the continuation of the Wi-Fi success story.[44]

III. THE COMMISSION SHOULD MOVE FORWARD EXPEDITIOUSLY WITH ITS PROPOSED CHANGES TO THE U-NII-1 TECHNICAL RULES.

In the *NPRM*, the Commission identified the U-NII-1 band as a strong candidate for improved spectrum sharing as part of its strategy for addressing unlicensed spectrum scarcity. Accordingly, it sought comment on proposals to increase the U-NII-1 maximum power limit and to allow outdoor use of U-NII devices.[45] There is strong record support for these proposals.

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[40] Comcast Comments at 3.

[41] Motorola Mobility Comments at 1; *see also* NCTA Comments at 9-10; TWC Comments at 8.

[42] Jon Brodkin, *Apple Brings 802.11ac Wi-Fi to AirPort Networking Hardware: Gigabit Wi-Fi Spreads Across the Apple Product Line*, ARS TECHNICA (June 10, 2013), http://arstechnica.com/apple/2013/06/apple-brings-802-11ac-wi-fi-to-airport-networking-hardware/.

[43] Motorola Mobility Comments at 1-2; NCTA Comments at 10.

[44] Cablevision Comments at 7; Cisco Comments at 6; Comcast Comments at 2-3; Google and Microsoft Comments at 1; Motorola Mobility Comments at 7; Motorola Solutions Comments at 13-14; SSC Comments at 3; TWC Comments at 2-3; Wi-Fi Alliance Comments at 6-7.

[45] *NPRM*, 28 FCC Rcd at 1782 ¶ 40.

Commenters almost unanimously favor adopting a higher power limit for U-NII-1 and removing the indoor-only restriction on U-NII-1 devices.[46] The commenters state that a higher transmit power limit in U-NII-1 will enable improved range, coverage, and better throughput for

[46] Cablevision Comments at 5-6 (stating that "[t]he Commission should adopt a unified 1W power level for U-NII-1 and U-NII-4 in order to harmonize those segments with U-NII-3," and that "[t]he Commission should remove the outdoor use restriction for U-NII-1"); CEA Comments at 11 ("Consistent rules, including rules allowing outdoor usage in the U-NII-1 sub-band, will help produce economies of scale in equipment design and manufacture . . ."); Cisco Comments at 54-55 (stating that "the Commission should harmonize the U-NII-1 power and PSD rules with those of UNII-2A at a minimum, and seriously explore possible harmonization with the U-NII-3 rules," and that "the Commission should explore elimination of the restriction on outdoor use for U-NII-1 devices"); Comcast Comments at 3 (stating that "[t]he Commission should . . . harmonize the rules for the U-NII-1 and U-NII-2 bands" and that "[t]he Commission should . . . remove the indoor-use restriction in the U-NII-1 band"); Letter from Michael McGeary, Co-founder, Engine Advocacy, et al., to Mignon L. Clyburn, Acting Chairwoman, Federal Communications Commission at 1 (filed May 28, 2013) ("[W]e encourage the FCC to grant commercial users the flexibility to use the 5 GHz band both indoors and outdoors, in order to raise and harmonize the power levels to improve transmission capability."); Comments of Ericsson at 5 ("Ericsson supports (1) increasing the power limits to 250 mW with a maximum EIRP of 30 dBm with 6 dBi antenna gain; (2) increasing the PSD limits to 11 dBm/MHz; and (3) eliminating the restriction on outdoor operation . . . .") (Ericsson Comments); Comments of Fastback Networks at 5 ("Fastback Networks fully supports removing the restriction on outdoor operation") (Fastback Networks Comments); Google and Microsoft Comments at 5-6 (stating that "the Commission should authorize outdoor as well as indoor use to the fullest extent possible, across all segments of the band," and that "the Commission should increase power levels and harmonize service rules across the various U-NII bands"); IEEE Comments at 4 (stating that the Commission should "[h]armonize the U-NII-1 rules to match the U-NII-2A rules, including elimination of 'indoor only' requirements"); ITIC Comments at 9 ("ITI supports harmonization of rules across UNII bands where possible, including raising power levels where possible and removing limitations on outdoor use."); Motorola Mobility Comments at 2 (indicating that the Commission should "[h]armoniz[e] the technical and operational rules applicable to the 5.15-5.25 GHz (U-NII-1) and 5.25-5.35 GHz (U-NII-2A) bands, including eliminating the restriction on outdoor operation of U-NII-1 devices"); Motorola Solutions Comments at 13 ("[T]he Commission should move forward with its proposals to harmonize regulatory treatment of unlicensed devices in the U-NII-3 and U-NII-1 bands, including by eliminating the unworkable distinction between 'indoor' and 'outdoor' operation in the U-NII-1 band."); TWC Comments at 10-11 (stating that "TWC believes the Commission can best serve consumers and promote the public interest by harmonizing U-NII-1 . . . with U-NII-3," and that "the Commission should have no indoor use restrictions"); Wi-Fi Alliance Comments at 25 ("[T]he Commission should, as proposed, increase the power limits . . ., and eliminate the restriction on outdoor operation.").

both indoor and outdoor operations, especially given the challenging propagation characteristics of the 5 GHz band as compared with the 2.4 GHz band.[47] Cablevision, for example, notes that "[a] 1W power level is needed to support reliable outdoor links due to signal blockage caused by bushes, trees, cars, etc."[48] Service providers and manufacturers alike support removing the indoor-use restriction to help meet skyrocketing consumer demand for outdoor Wi-Fi networks.[49] Without these important changes, the U-NII-1 band will remain virtually unusable for cable Wi-Fi operations.

Globalstar is the only company using the entire 100 megahertz U-NII-1 band. It opposes the Commission's proposed rule changes, arguing that allowing more intensive and efficient use of the band would conflict with its use of the band for mobile satellite service (MSS) feeder links.[50] Globalstar's use of the band, however, is substantially different from the use of the band envisioned by the Commission when it established the U-NII-1 rules more than a decade ago. Furthermore, Globalstar's technical assertions regarding the interference potential of higher-power, outdoor U-NII devices are greatly overstated and based on unreasonable assumptions. The Commission should disregard those assertions.

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[47] Cablevision Comments at 5; Comcast Comments at 27-28; Google and Microsoft Comments at 6; Motorola Mobility Comments at 5; NCTA Comments at 14; TWC Comments at 12; Wi-Fi Alliance Comments at 24-25.

[48] Cablevision Comments at 5.

[49] Cablevision Comments at 6; Comcast Comments at 25-26; Fastback Networks Comments at 5; Google and Microsoft Comments at 5; ITIC Comments at 10; Motorola Mobility Comments at 5; Motorola Solutions Comments at 4; NCTA Comments at 15-16; TWC Comments at 10-11; Wi-Fi Alliance Comments at 24-25; Comments of the Wireless Internet Service Providers Association at 9 (WISPA Comments).

[50] Globalstar Comments at 4-6.

The Commission first authorized Globalstar to operate in the Big Low Earth Orbit (LEO) band in 1995.[51] At that time, the Commission predicted that the nascent mobile satellite service would "create a new industry providing enormous economic benefit to the United States," that would "offer an almost limitless number of services, including ubiquitous voice and data mobile services, position location services, search and rescue communications, disaster management communications, environmental monitoring, paging services, facsimile transmission services, cargo tracking, and industrial monitoring and control."[52] One applicant in the Big LEO proceeding predicted "that by 2001 the demand for user transceivers will be 1.3 million in the United States and 4.7 million worldwide."[53]

It is now clear that the Commission's assumption that there would be intense and efficient MSS use of U-NII-1 was incorrect. Today, even with the benefit of twenty years to bring the band into use, Globalstar's entire Big LEO satellite system serves only 550,000 customers worldwide, of which only a portion are likely to be U.S. customers.[54] Moreover, only Globalstar's duplex service uses the U-NII-1 band for uplink and Globalstar has less than 100,000 worldwide subscribers to its duplex service.[55] To put these numbers in context,

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[51] *Id.* at 2.

[52] *Amendment of the Commission's Rules to Establish Rules and Policies Pertaining to a Mobile Satellite Service in the 1610-1626.5/2483.5-2500 MHz Frequency Bands*, CC Docket No. 92-166, Report and Order, 9 FCC Rcd 5936, 5939-40 ¶¶ 1, 3 (1994).

[53] *Id.* at 5940 ¶ 4.

[54] *See* Globalstar Comments at 2.

[55] Globalstar Annual Report, FORM 10-K (Mar. 15, 2013), *available at* http://www.globalstar.com/en/index.php?cid=6060&page=2 (stating that Globalstar had only 88,189 duplex subscribers in 2012); Rob Alderfer, Dirk Grunwald and Kenneth Baker, *Toward Expanded WiFi Access in the 5 GHz Band*, CABLELABS/University of Colorado, at 66 & n.69 (July 2013) (included as Attachment) (stating that Globalstar's duplex service uses the 5.2 GHz band for uplink, while Globalstar's simplex and SPOT services use different bands for uplink and downlink).

manufacturers sold over 1.5 billion new Wi-Fi devices worldwide in 2012.[56] That means that while Globalstar's worldwide customer base after 20 years is 550,000, consumers purchase 550,000 new Wi-Fi enabled devices *every three and one-half hours*.

Importantly, the Commission set rules based on the assumption that many different MSS companies would share the U-NII-1 band. In contrast, today Globalstar is the only satellite operator that operates feeder link stations in the 5096-5250 MHz band domestically,[57] and it operates *only four feeder link facilities in the entire country*.[58] Furthermore, Globalstar's operations are inefficient, particularly when compared with Wi-Fi. Globalstar transmits at only 9.6 kilobits per second, which is suitable primarily for voice communications.[59] Wi-Fi operates 1,900 times more efficiently.[60] Thus, it is perhaps not surprising that Globalstar has petitioned the Commission to permit it to use its Big LEO spectrum in another band for Wi-Fi-like service,

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[56] *Wi-Fi Enabled Device Shipments will Exceed 1.5 Billion in 2012, Almost Double that Seen in 2010*, ABI RESEARCH (Oct. 11, 2012), http://www.abiresearch.com/press/wi-fi-enabled-device-shipments-will-exceed-15-bill.

[57] *Globalstar Licensee LLC, Application for Modification of Non-geostationary Mobile Satellite Service Space Station License; GUSA Licensee LLC, Applications for Modification of Mobile Satellite Service Earth Station Licenses; GCL Licensee LLC, Applications for Modification of Mobile Satellite Service Earth Station Licenses*, File Nos. SAT-MOD-20080904-00165 *et seq.*, Order, 26 FCC Rcd 3948, 3949-50 ¶ 2 n.1 (Int'l Bur. 2011) (*Globalstar 2011 Application Order)* (noting that the only other Big LEO system licensed by the Commission – Iridium's system – "is designed with Time Division Multiple Access architecture and uses the 1617.775-1626.5 MHz band for transmission in both directions between satellites and mobile terminals" and therefore does not use the U-NII-1 band for uplinks); *NPRM*, 28 FCC Rcd at 1781 ¶ 38 & n.47.

[58] *See Globalstar 2011 Application Order*, 26 FCC Rcd at 3949 ¶ 3 n.3 (noting that Globalstar's feeder uplink stations are located in Cabo Rojo, Puerto Rico; Clifton, Texas; Sebring, Florida; and Wasilla, Alaska).

[59] *Description of the Globalstar System*, Globalstar at 1-2, 1-8 (Dec. 7, 2000), *available at* http://gsproductsupport.files.wordpress.com/2009/04/description-of-the-globalstar-system-gs-tr-94-0001-rev-e-2000-12-07.pdf.

[60] *See* Alderfer *et al.*, *supra* note 55, at 67.

instead of merely for MSS. With this request, Globalstar appears to recognize that there is a more efficient and valuable use of the spectrum than the provision of only MSS.[61]

The Commission should change the U-NII-1 technical rules in light of the substantial differences between the predicted MSS use of the U-NII-1 band and the reality of MSS use today. In doing so, the Commission should recognize that Globalstar, by opposing reasonable technical rule changes, is asking the Commission effectively to reserve 100 megahertz of spectrum for four feeder link stations in a system that provides narrowband voice or data service to only a small number of domestic customers. Allowing such an inefficient use of a large and valuable band by a single company – that neither acquired the spectrum through an auction, nor is required to comply with an efficient sharing protocol such as Wi-Fi – is unacceptable given the growing spectrum scarcity.

Importantly, NCTA proposes that the Commission adjust the U-NII-1 technical rules to allow reasonable sharing of the band by unlicensed devices, rather than relocate Globalstar's limited operations. The Commission could thereby allow Globalstar to use the band for its four feeder link facilities while also giving consumers access to the band for widespread Wi-Fi services – resulting in a more intensively and efficiently used band.

Globalstar appears to contend that any increase in power or outdoor use would be inconsistent with its use of the band.[62] This is incorrect for two reasons. First, Globalstar's technical assertions regarding the interference potential of higher-power, outdoor U-NII devices are overstated and based on unreasonable assumptions. Second, Globalstar's analysis looks only at the potential impact on Globalstar's 5 GHz feeder uplink signal, and fails to analyze whether

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[61] *See* Petition for Rulemaking of Globalstar, Inc., RM-11685 (filed Nov. 13, 2012).

[62] Globalstar Comments at 4-6.

there would be actual harmful interference to MSS end-user devices taking into account Globalstar's system as a whole.

Globalstar's technical assertions are unrealistic for a variety of reasons. Globalstar assumes, for example, that every satellite in its system is somehow positioned directly above every potential unlicensed device in the country every minute of the day. This is clearly impossible. Furthermore, Globalstar's analysis assumes that there will never be a building, foliage, or other obstruction attenuating any U-NII access point signal that might reach any of its satellites. Moreover, Globalstar's analysis relies on ITU Recommendations on interference limits that may not accurately reflect how much interference Globalstar's system can tolerate.[63] Globalstar also makes incorrect assumptions about the antenna gain of outdoor Wi-Fi access points, and fails to account for Wi-Fi duty cycles and U-NII-1 channelization.[64]

In reality, a satellite will rarely operate directly above any given U-NII access point, and in fact, will often operate at a much different elevation angle.[65] Studies show that over 88 percent of the time, a Globalstar satellite will be observed between a 30 degree and a 60 degree elevation angle above the horizon at an earth latitude of 41.9 degrees (approximately the latitude of Denver, Colorado).[66] This relatively straightforward observation alone renders Globalstar's analysis incorrect.[67] A terrestrial Wi-Fi access point also would have no reason to point an antenna directly at the sky, since that is not where consumers are located. Accordingly, most access points do not have a direct line of sight to a satellite with an elevation angle of 30 to 60

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[63] Alderfer *et al.*, *supra* note 55, at 26.

[64] *See* Globalstar Comments at Appendix; Alderfer *et al.*, *supra* note 55, at 23-24, 26-28.

[65] Alderfer *et al.*, *supra* note 55, at 25.

[66] *Id.*

[67] *See id.*

degrees, and signals from such access points are far more likely to face obstacles like buildings and foliage that would limit their visibility to a satellite.[68] Globalstar's analysis completely fails to account for any Wi-Fi signal attenuation.

Moreover, it is unlikely that the ITU noise floor used in Globalstar's analysis accurately reflects the realities of Globalstar's system. For example, if Globalstar has fewer U.S. users than assumed before the launch of its satellites, its system may be capable of tolerating a higher level of interference.[69] In addition, advances in forward error correction coding or improvements to link budget margins with the launch of second generation satellites might also mean that the ITU recommendation is no longer an accurate measure of the interference that satellites can tolerate.[70] Also, as Cisco correctly points out, the Commission should have "serious questions" about the continued viability of Globalstar's interference model given the substantial differences between this model and the U-NII deployment model set forth in Appendix B of NTIA's 5 GHz Report.[71]

In addition, contrary to Globalstar's assumptions, outdoor access point antennas in the real world have less antenna gain pointing directly up than at the horizon. Indeed, assuming a 30 degree elevation angle, most Wi-Fi antennas would operate with 10 dB less gain than what Globalstar proposed, while a Wi-Fi antenna would operate with 15 dB less gain at the zenith.[72]

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[68] *See id.*

[69] *Id.* at 26.

[70] *Id.*

[71] *See* Cisco Comments at 56-57. Cisco refers to the interference model Globalstar used in the 1997 proceeding. It appears that Globalstar's analysis here is virtually the same as the analysis it submitted in 1996. *See* Comments of L/Q Licensee, Inc., ET Docket No. 96-102, at 8 (July 15, 1996) (asserting that "only 1070 simultaneous users of NII/SuperNet devices operating in the 5150-5250 MHz band in the continental United States would be required to produce noticeable interference" to Globalstar).

[72] Alderfer *et al.*, *supra* note 55, at 24.

Moreover, while the interference study performed by satellite operators in 1996 assumed a duty cycle of 10 percent for the activity of U-NII-1 access points, Globalstar fails to account for Wi-Fi duty cycles entirely.[73] As the attached analysis shows, incorporating a 10 percent duty cycle into Globalstar's analysis would alone increase by ten times the number of U-NII access points that Globalstar estimates could operate without causing harmful interference to its operations.[74] In addition, Globalstar fails to account for U-NII-1 channelization. Because there are four 20 megahertz channels currently defined by the IEEE in the U-NII-1 band, Globalstar's estimated number of access points can be multiplied by four before reaching the noise floor.[75] All of these deficiencies mean that the Commission can enable expanded Wi-Fi operations in U-NII-1 without causing potentially harmful impacts to the noise floor at the satellite receiver.

But Globalstar's arguments also are incorrect for a more fundamental reason. Globalstar inappropriately restricted its analysis only to the potential impact at the satellite feeder link uplink receiver in space. A more complete and accurate analysis should take into account Globalstar's entire system, including the downlink that ultimately delivers the signal to the end user. Without such an analysis, Globalstar's assertions about the impact of the Commission's proposed rules changes in U-NII-1 are unreliable.

Globalstar's system is a "bent pipe," with no processing taking place on board the satellite. The satellite simply converts the 5 GHz feeder uplink signal to the 2.5 GHz downlink signal for delivery to satellite phones.[76] Therefore, the performance of the satellite phone, not an

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[73] *Id.* at 26-27.

[74] *Id.* at 27.

[75] *Id.*

[76] *Id.* at 28.

arbitrary measure of a single intermediate link in the network, is the relevant point at which to assess any potential impact to Globalstar's system.

As the attached analysis demonstrates, the signal of the feeder link, which shares the 5 GHz band with Wi-Fi, is much stronger than the signal of Globalstar's 2.5 GHz downlink.[77] Specifically, the uplink signal – which is generated from the feeder link gateway using a high-powered amplifier in combination with a large 5.5 meter parabolic antenna – is approximately 76 times stronger than the downlink.[78] *This means that the limiting link in Globalstar's system is in its downlink band, and not the 5 GHz feeder link*. Therefore, looking at Globalstar's operations on a more appropriate whole-system basis, the uplink can accommodate significant noise without affecting overall system performance in a way that would impact the end-user experience.[79]

As a result, adoption of the Commission's proposed new U-NII-1 technical rules, even with significant deployment on terms equivalent to U-NII-3, poses little to no risk to Globalstar's system.[80] In fact, as described in detail in the attached CableLabs/University of Colorado paper, many millions – if not billions – of Wi-Fi access points can operate outside in U-NII-1 with a maximum power of 1 watt without causing harmful interference to Globalstar users.[81] For this reason, the Commission should disregard the technical analysis submitted by Globalstar, and move expeditiously to expand Wi-Fi access in U-NII-1.

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[77] *Id.* at 29-31.

[78] *Id.*

[79] *Id.* at 31-33.

[80] *Id.* at 33-34.

[81] *Id.*

IV. THE COMMISSION SHOULD MOVE FORWARD EXPEDITIOUSLY TO OPEN THE U-NII-4 BAND FOR UNLICENSED USE.

The Commission also proposed to designate the U-NII-4 band for use by unlicensed devices to address the pressing need for additional spectrum resources for wireless broadband. Furthermore, the Commission proposed to adopt technical rules that would harmonize the U-NII-3 and U-NII-4 bands.[82] NCTA and a wide array of commenters support these proposals. Importantly, supporters of unlicensed use of the band and most incumbents agree that manufacturers, technology companies, ITS interests, satellite interests, and government users can and should work together and with the Commission to create appropriate sharing mechanisms. Doing so in a timely manner is critical because the country cannot afford to leave the U-NII-4 band as greatly underutilized as it is today when confronting the unlicensed spectrum shortage challenge. Therefore, the Commission should reject commenters' calls to delay efforts to increase efficiency and intensity of use in this band.

A. Commenters Demonstrate that Designating U-NII-4 for Unlicensed Use and Harmonizing Technical Rules with U-NII-3 Would Produce Substantial Benefits for Consumers.

The record in this proceeding establishes broad support for the Commission's proposal to permit unlicensed operations in U-NII-4.[83] Commenters agree with the Commission that the 5 GHz band is uniquely situated to accommodate spectrum sharing with unlicensed devices.[84]

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[82] *NPRM*, 28 FCC Rcd at 1798-99 ¶ 97.

[83] CEA Comments at 14; Cisco Comments at 57; Ericsson Comments at 9; Fastback Networks Comments at 11; Google and Microsoft Comments at 4; IEEE Comments at 28; ITIC Comments at 5-6; Motorola Mobility Comments at 2; Motorola Solutions Comments at 9; Qualcomm Comments at iii; SSC Comments at 3; Comments of the Telecommunications Industry Association at 3 (TIA Comments); Wi-Fi Alliance Comments at 27; WISPA Comments at 7-8.

[84] Comcast Comments at 29-30; Motorola Mobility Comments at 1; NCTA Comments at 19.

Comcast, for example, notes that "there will never be a better time to empower sharing of the U-NII-4 band than today, or a better band to actualize the Administration's forward-looking policy of advancing spectrum sharing."[85] Comcast further notes that "the 5 GHz band has more potentially available spectrum for unlicensed technologies than any other band being considered for an unlicensed designation in the United States today."[86] Likewise, the CEA states that "[t]he 5 GHz band's wide expanse of underutilized spectrum is particularly well-suited for emerging wireless broadband technologies."[87]

Commenters also explain that it is important for the Commission to establish technical rules for the U-NII-4 band that are as similar as possible to the current rules for the U-NII-3 band to facilitate a contiguous 160-megahertz, 802.11ac-based channel, spanning the two bands to enable support for gigabit Wi-Fi. In particular, commenters demonstrate that in order to allow widespread Wi-Fi networks that could serve millions of Americans, the Commission should:

1. Permit outdoor operation; and
2. Establish a power limit of 1 watt.

For example, in urging the Commission to harmonize U-NII-4 with existing U-NII-3 rules, Time Warner Cable observes that "the current rules for the U-NII-3 band – with higher power levels than permitted elsewhere at 5 GHz, no indoor use restrictions, and no dynamic frequency selection (DFS) requirements – have proven ideal for outdoor Wi-Fi deployments."[88] Cablevision notes that a "1W power level is needed to support reliable outdoor links due to signal blockage" and argues that "indoor-only restrictions are unnecessary and impede one of the

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[85] Comcast Comments at 29.

[86] *Id.* at 2.

[87] CEA Comments at 2.

[88] TWC Comments at 3.

most effective and growing applications for WiFi—outdoor use."[89] Likewise, Ericsson "supports the Commission's proposal [to] apply similar rules across the entire U-NII-3 and -4 bands."[90] The Wi-Fi Alliance also agrees that "the U-NII-3 rules should apply across the entire 200 megahertz of spectrum that will comprise the (expanded) U-NII-3 and U-NII-4 bands," consistent with the need not to interfere with licensees.[91]

B. Most Commenters Agree that Technology Companies and ITS Interests Can and Should Work Together with the Commission to Establish Sharing Mechanisms that Promote Broadband Without Causing Harmful Interference.

NCTA understands the beneficial role that ITS systems could play for transportation safety in the future. We agree that the Commission's rulemaking must result in an environment where unlicensed devices do not cause harmful interference to ITS licensees once companies make such systems available. Most commenters, including many ITS interests, acknowledge the need for all parties to work together to balance protection for these future ITS deployments with the immediate need for additional unlicensed spectrum.[92] For example, Ford Motor Company notes that it is "fully committed to working with the proponents of U-NII use to evaluate the

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[89] Cablevision Comments at 5, 6.

[90] Ericsson Comments at 10; *see also* Fastback Networks Comments at 11 ("Fastback Networks fully supports the Commission's proposal to harmonize the U-NII-4 band rules with those of the proposed revised U-NII-3 band rules.").

[91] Wi-Fi Alliance Comments at 27.

[92] Comments of American Association of State Highway & Transportation Officials at 18 (AASHTO Comments); Comments of the Alliance of Automobile Manufacturers, Inc. and the Association of Global Automakers, Inc. at 33 (Alliance of Auto Manufacturers Comments); Comcast Comments at 30; Comments of Ford Motor Company at 3 (Ford Comments); ITIC Comments at 9; Comments of Intelligent Transportation Society of America at 40 (ITSA Comments); Comments of Mercedes-Benz USA, LLC at 3 (Mercedes-Benz Comments); NCTA Comments at 18; Comments of SAE International at 2; Comments of Savari Networks at 35; Comments of the Toyota Motor Corporation at 16 (Toyota Comments); TWC Comments at 12; Wi-Fi Alliance Comments at 26-27.

prospect of coexistence with [dedicated short-range communications] DSRC."[93] Likewise, AASHTO declares that it "seeks a balanced solution that will not compromise the ongoing DSRC efforts . . . while still allowing DSRC spectrum sharing that would bring additional commercial Internet applications and solutions to unlicensed Wi-Fi devices."[94] The Honorable Deborah Hersman, Chairman of the National Transportation Safety Board, states that the NTSB "is not opposed to sharing in principle," so long as the Commission can ensure the security of uses relating to transportation safety.[95]

We cannot, however, delay this effort. ITS interests have not yet deployed any commercial systems and are still in the process of designing and testing their technologies. This makes the U-NII-4 band a far better candidate for sharing than almost any other band where sharing is possible. This is the case because ITS licensees and U-NII-4 unlicensed systems both are still in pre-deployment – which is not the case in other bands. In U-NII-4, therefore, ITS and unlicensed companies alike are in a perfect position to effectuate sharing by building sharing into systems from the beginning of their deployments.

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[93] Ford Comments at 2. Similarly, Toyota states, "While Toyota is not conceptually opposed to sharing this spectrum with unlicensed U-NII devices in the future, the Commission must work with other federal agencies and all affected private sector constituencies to ensure that there is minimal interference risk attending the co-existence of DSRC systems and U-NII devices at any given moment." Toyota Comments at 1-2; *see also* Comcast Comments at 29-30; Ericsson Comments at 10; Fastback Networks Comments at 11; Google and Microsoft Comments at 10; IEEE Comments at 30; ITIC Comments at 8; Motorola Mobility Comments at 8; NCTA Comments at 18; Qualcomm Comments at 3; TWC Comments at 12; WISPA Comments at 7-8.

[94] AASHTO Comments at 15.

[95] Letter from Deborah A.P. Hersman, Chairman, National Transportation Safety Board, to Mr. Aole Wilkins, Electronics Engineer, Office of Engineering and Technology, Federal Communications Commission, ET Docket No. 13-49, at 3 (filed May 28, 2013).

But until the Commission makes clear that it plans to open U-NII-4 for unlicensed use, ITS companies have no incentive to work with unlicensed proponents on methods for sharing the 5.9 GHz band to allow more efficient and intensive use of the band. To make sharing in U-NII-4 a reality, therefore, the Commission should first state its intent to permit unlicensed use in the 5850-5925 MHz band, and then request comments on the appropriate approach to sharing. In this way, the Commission can, as some ITS proponents suggest,[96] conduct further proceedings on the technical parameters for sharing in an environment where all parties have an incentive to work together toward a solution.

Now is the time, before ITS equipment is certified and widely deployed, for the Commission to work with technology companies and ITS companies to put in place a sharing approach that will permit unlicensed users and ITS to share U-NII-4. The President, in his recent spectrum memorandum, noted the success of information sharing and discussions between agencies and non-federal stakeholders, and directed NTIA to "continue to facilitate these discussions and the sharing of data to expedite commercial entry into these bands where possible . . . through acceptable sharing arrangements."[97] If the Commission postpones a decision on unlicensed use in U-NII-4 until ITS deploys commercial systems, it will become substantially more difficult and costly to develop and deploy sharing mechanisms. And because an ITS deployment could take decades, and is far from certain to occur at all, this would result in the U-NII-4 band remaining substantially underutilized for far too long. An acceptable sharing

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[96] Alliance of Auto Manufacturers Comments at 3, 8; Ford Comments at 3; Mercedes-Benz Comments at 3; *cf.* ITSA Comments at 40.

[97] Presidential Memorandum, Expanding America's Leadership in Wireless Innovation, 78 Fed. Reg. 37431, 37432 (June 14, 2013).

mechanism is achievable if technology companies and ITS interests work together now to design sharing and interference protection from the beginning of their deployments.

C. ITS Proponents Overstate the Risk of Potential Interference to ITS from Wi-Fi.

ITS proponents have overstated the risk of potential interference to ITS if Wi-Fi devices were permitted to operate in U-NII-4. As the attached analysis explains,[98] the hyperbolic interference scenarios described by, for example, the American Association of State Highway and Transportation Officials (AASHTO) improperly assume that any potential impact to ITS operations will be "harmful interference."[99] This will not be the case. For interference to be harmful under Commission rules, it must "endanger[] the functioning of a radionavigation service or . . . other safety services" or "seriously degrade[], obstruct[], or repeatedly interrupt[] a radiocommunications service."[100] AASHTO maintains that its analysis demonstrates that a single 802.11ac access point at an elevation of 100 feet in Virginia Beach would cause interference along 10 miles of I-264.[101] As the attached study points out, however, applying the same assumptions AASHTO has used to existing Wi-Fi operations would mean that operating even "a single Wi-Fi access point would undermine the operation of all other Wi-Fi devices within 10 miles," a scenario clearly not experienced by real-world Wi-Fi users.[102]

As the attached study discusses, DSRC Basic Safety Messages emitted from multiple vehicles in close proximity already interfere with each other, but manage to get through most of

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[98] Alderfer *et al.*, *supra* note 55, at 46-47.

[99] AASHTO Comments at 11-15.

[100] 47 C.F.R. § 2.1.

[101] AASHTO Comments at 15.

[102] Alderfer *et al.*, *supra* note 55, at 47.

the time by relying on probabilistic recovery over several attempts at transmission.[103] Any interference that might be caused by Wi-Fi would merely be "on the margin, in combination with other environmental noise factors that exist today," and, with appropriate sharing technology in place, would not seriously degrade, obstruct or interrupt DSRC operations.[104]

D. Technical Analysis Demonstrates that Unlicensed Consumer Devices Should Be Able to Share U-NII-4 with C-Band Satellite Operations Without Causing Harmful Interference.

As the Commission notes in the *NPRM*, the extended C-band is only "lightly used" by the fixed satellite service (FSS).[105] This is because, as Intelsat and SES acknowledge, a footnote in the U.S. table of allocations restricts any extended C-band use "to international inter-continental systems . . . subject to case-by-case electromagnetic compatibility analysis."[106] Indeed, due to this substantial limitation, Commission policy governing extended C-band use anticipates that only "*one earth station on each coast*" can be put in place.[107]

Based on the modeling studies in the attached CableLabs/University of Colorado paper, U-NII devices do not pose an interference risk to this lightly used service. As a threshold matter, operations in close proximity to earth stations should not cause interference, since extended C-band earth stations in the U-NII-4 band transmit rather than receive, and do so using highly directional antennas pointed towards the geostationary orbital arc. Instead, as Intelsat and SES concede, the only interference that could occur would have to come from the aggregate effects of

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[103] *Id.* at 47-50.

[104] *Id.* at 50-51.

[105] *NPRM*, 28 FCC Rcd at 1797 ¶ 90.

[106] 47 C.F.R. § 2.106 Table of Allocations, footnote US 245. Comments of SES S.A. and Intelsat S.A. at 4 n.7 (SES and Intelsat Comments).

[107] 47 C.F.R. § 2.108 (emphasis added).

U-NII-4 devices operating at power levels that would prevent an FSS satellite from identifying the earth station signal from among the noise.[108] As the attached CableLabs/University of Colorado paper explains, because FSS satellites are very far from earth (much further away than MSS satellites that operate in U-NII-1, for example), the potential for such interference is very low.[109]

As Intelsat and SES acknowledge, the Commission already has authorized DSRC devices to operate in the U-NII-4 band alongside extended C-band operations. Unlicensed Wi-Fi devices, like DSRC devices, operate using IEEE 802.11 standards.[110] Unlike unlicensed Wi-Fi devices, however, DSRC roadside units can transmit from 2 watts up to 30 watts in some instances – several times the maximum power limit proposed by the Commission for unlicensed operations.[111]

Intelsat and SES attempt to distinguish DSRC and U-NII operations by arguing that the number of DSRC devices is expected to be around 600,000 to 2 million, and Wi-Fi deployments could be far greater.[112] If the Department of Transportation truly intends to deploy DSRC roadside units along all major roadways, however, many more units will be required, given the

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[108] *See* SES and Intelsat Comments at 3-4. Unlicensed operations in U-NII-4 will also have to protect FSS uplink operations in the adjacent C-band (5.925-6.425 GHz) from interference; however, based on available information, we believe that the risks posed by such out of band emissions by unlicensed services operating in U-NII-4 are more remote than the risk posed to in-band FSS operations.

[109] Alderfer *et al.*, *supra* note 55, at 56-57.

[110] Cisco Comments at 63; IEEE Comments at 29-30; Wi-Fi Alliance Comments at 26.

[111] Roadside DSRC units usually have a maximum output power of 33 dBm (2 watts), and up to 44.8 dBm (30 watts) for the Control Channel. 47 C.F.R. § 90.377. In the *NPRM*, the Commission proposes a power limit of 1 watt for U-NII devices operating in U-NII-4. *NPRM*, 28 FCC Rcd at 1798-99 ¶ 97.

[112] SES and Intelsat Comments at 8 & n.23.

range limitations of 100-1,000 meters for roadside units. Yet satellite interests have not expressed concern about the potential for mass proliferation of DSRC roadside units operating at a higher power than Wi-Fi devices.

In fact, based on the attached analysis, there is little reason for Intelsat and SES to be concerned about the risk of interference from Wi-Fi in U-NII-4. Because their satellites are geostationary and orbit near equatorial latitude, there is great distance between Wi-Fi access points that will be deployed in U-NII-4 and their satellite receivers. SES and Intelsat's satellites orbit at over 35,000 kilometers above the Earth.[113] This is a far greater height than mobile satellites in U-NII-1, which Globalstar notes are only 1,400 kilometers from the Earth at their closest orbital point.[114] As noted by Alderfer *et al*, this distance differential entails significant signal spreading loss, such that Wi-Fi signals will be approximately 640 times weaker at the SES and Intelsat satellite receivers relative to Globalstar's satellite receivers.[115] Given that there is little risk to Globalstar's system from expanding Wi-Fi access, there should be proportionally less risk to SES and Intelsat systems. Therefore, no special protections are required for the fixed satellite service as the Commission expands Wi-Fi access into U-NII-4.

V. THE COMMISSION SHOULD HARMONIZE U-NII-3 TECHNICAL RULES.

Every commenter that addresses the Commission's proposal to extend the U-NII-3 band by an additional 25 megahertz supports the Commission's approach.[116] As NCTA stated in its

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[113] Alderfer *et al.*, *supra* note 55, at 56.

[114] *Id.* at 56-57; Globalstar Comments at Appendix.

[115] Alderfer *et al.*, *supra* note 55, at 56-57.

[116] Cisco Comments at 42; Comcast Comments at 24; Ericsson Comments at 4; Fastback Networks Comments at 2; Comments of First Step Internet, LLC at 3 (First Step Comments); IEEE Comments at 26; Motorola Mobility Comments at 2; NCTA Comments at 17;

opening comments, extending U-NII-3 will provide additional Wi-Fi-suitable spectrum for consumers and will facilitate the use of a 160-megahertz contiguous 802.11ac-based channel once the Commission designates U-NII-4 for unlicensed use. The Commission's proposal will "eliminate the disparity and decrease the complexity associated with interpreting [the Commission's] rules for digitally modulated devices operating in the U-NII-3 band under Section 15.407 and in the 5.725-5.85 GHz band under Section 15.247" and will help to avoid interference created when devices are modified to operate outside the bands for which the Commission has certified them.[117]

Specifically, the Commission proposes to follow the section 15.247 rules for maximum power, power spectral density, and emission bandwidth, while retaining the section 15.407 rules for antenna gain, unwanted emissions, and peak-to-average ratio.[118] In NCTA's view, the majority of these proposed changes to U-NII-3 will not prove burdensome, and NCTA does not oppose adopting them in order to streamline the rules.

However, like other commenters, NCTA requests that the Commission adopt rule changes for U-NII-3 that will permit the continued operation of point-to-point wireless backhaul links that currently allow network operators to deploy wireless networks where access points are not sufficiently close to a wired network to permit direct connection.[119] In particular, NCTA requests that the Commission adopt the part 15.247 rule for antenna gain, which will permit network operators to continue to deploy broadband services to rural communities.

Comments of SPITwSPOTS, Inc. at 3 (SPITwSPOTS Comments); TIA Comments at 11; TWC Comments at 9; Wi-Fi Alliance Comments at 11; WISPA Comments at 12.

[117] *NPRM*, 28 FCC Rcd at 1778 ¶ 26.

[118] *Id.* at 1779-80 ¶¶ 30-35.

[119] Fastback Networks Comments at 3-4; First Step Comments at 4-5; SPITwSPOTS Comments at 4; TWC Comments at 13; WISPA Comments at 12-14 .

VI. CONCLUSION.

The 5 GHz band presents the Commission with a unique opportunity to make a large amount of currently underutilized spectrum available for widespread unlicensed use to help address the rapid increase in demand for wireless broadband. But the Commission can, and should, act now to enable unlicensed use wherever possible. In particular, the Commission should: (1) promptly permit outdoor operation and a higher transmit power limit in U-NII-1; (2) permit unlicensed operations in U-NII-4 and conduct further proceedings on the technical parameters for sharing; and (3) extend the upper edge of the U-NII-3 band by 25 megahertz and adopt uniform technical rule changes for the band that will not prevent point-to-point wireless backhaul operations. Doing so will facilitate unlicensed broadband operations and encourage technical solutions to enable currently underutilized portions of the band to be used as efficiently as possible.

Respectfully submitted,

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Attachment

Toward Expanded Wi-Fi Access in the 5 GHz Band

Rob Alderfer, CableLabs

Dirk Grunwald and Kenneth Baker, University of Colorado

Abstract

Wi-Fi is critical to the nation's wireless broadband goals, by some estimates carrying more than half of all Internet traffic. However, robust Wi-Fi growth risks a wireless capacity shortage, and the latest mass-market Wi-Fi technology, known as 802.11ac, is constrained by inadequate spectrum access. The FCC has proposed to expand Wi-Fi access in the 5 GHz band to address these issues.

The 5 GHz Wi-Fi band is shared with several other services. This paper analyzes the interference risk to certain incumbent services posed by expanding Wi-Fi access, with a particular focus on two sub-bands known as UNII-1 and UNII-4. We find that interference analyses submitted by incumbent interests are faulty and substantially overstate the risk of interference. We demonstrate how accurate analysis illustrates many potential paths to coexistence between Wi-Fi and incumbent services. We also suggest areas for further research to this end, with the goal of preserving and enhancing the high consumer benefits of Wi-Fi.

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1 Executive Summary

Expanding wireless broadband access has become an important national goal. The FCC's National Broadband Plan observed, "broadband is a foundation for economic growth, job creation, global competitiveness and a better way of life."[1]

Wi-Fi is a key component of the wireless broadband ecosystem. By some estimates, Wi-Fi handles more data traffic than any other medium, including mobile and fixed lines.[2] Over half of the traffic from mobile devices travels over Wi-Fi,[3] indicating how crucial Wi-Fi is to wireless consumers and the growth of mobile broadband. Globally, Wi-Fi is estimated to result in a total economic gain for households of between $52 billion and $99 billion annually.[4]

However, Wi-Fi risks spectrum exhaustion as usage – and its importance to consumers – grows. Only two wireless bands carry the Wi-Fi traffic that is so crucial to our innovation economy. The 2.4 GHz Wi-Fi band is nearing exhaustion in congested markets, and most of the 5 GHz Wi-Fi band is complicated by rules that limit its use.

Wi-Fi technology is continuing to improve and provide better user experiences. 802.11ac, the latest mass market IEEE Wi-Fi standard, can provide gigabit speeds – throughput over three times current technology. However, this standard uses wider channels and more spectrum, exacerbating regulatory complexity that exists today in the 5 GHz band. In fact, current rules will not allow US consumers to take full

[1] FCC, NATIONAL BROADBAND PLAN, xi (2010).

[2] John Solit, *How Much Traffic Does Wi-Fi Carry in America?* NCTA CABLE TECH TALK (Feb. 8, 2013), http://www.cabletechtalk.com/broadband-internet/broadband/question-how-much-data-is-carried-over-wi-fi/.

[3] NITIN BHAS, MOBILE DATA OFFLOAD & ONLOAD: WI-FI & SMALL CELL STRATEGIES 2012-2016 (Juniper Research 2013), *see* http://www.juniperresearch.com/viewpressrelease.php?pr=316.

[4] RICHARD THANKI, THE ECONOMIC SIGNIFICANCE OF LICENSE-EXEMPT SPECTRUM TO THE FUTURE OF THE INTERNET 8 (June 2012).

advantage of this new technology, since optimal channel bandwidths exceed the current amount of contiguous, harmonized Wi-Fi spectrum in the 5 GHz band. Recognizing this, the FCC has proposed reforms that would enable greater Wi-Fi use of 5 GHz spectrum.

Enhancing Wi-Fi access to 5 GHz frequencies – both expanding the Wi-Fi allocation in the band, and making current allocations more useful – is necessary to ensure continued growth of wireless broadband.

Wi-Fi shares the 5 GHz band with several other services. Coexistence with incumbent spectrum users of the 5 GHz band is therefore needed to realize enhanced Wi-Fi access. This paper analyzes the interference issues that will form the basis for coexistence mechanisms. We pay particular attention to the deployment of residential and commercial Wi-Fi systems since they represent the widest use of the UNII spectrum. Other 5 GHz Unlicensed National Information Infrastructure (UNII) systems and applications, such as those used by Wireless Internet Service Providers (WISPs), may benefit from further analysis.

We focus in particular on the UNII-1 and UNII-4 sub-bands, representing the bottom and top ends of the 5 GHz Wi-Fi band, since sufficient incumbent system information is available for a fulsome exploration in this area, and since we find substantial flaws in the analysis presented to date by the incumbent interests there.

In particular, we find that:

1) The Mobile Satellite System incumbent that occupies UNII-1, Globalstar, makes several technical errors in evaluating the likelihood of co-band Wi-Fi access point 'noise' breaching a conservative noise floor standard, rendering their analysis unreliable. In addition, we demonstrate that a comprehensive whole-system interference analysis, which Globalstar fails to present in favor of a narrow single-link analysis, shows that expansion of Wi-Fi uses poses very little, if any, risk to their system.

2) The Intelligent Transportation System that is envisioned for deployment in UNII-4, but has yet to be implemented, is duplicated in many respects by commercially available technology, and the ubiquitous adoption required for its efficacy is uncertain. To the extent that the concept is widely implemented, we conclude that coexistence with Wi-Fi is possible through the IEEE 802.11 process, on which both technologies are based.
3) Though little system information is available on Federal radars that span multiple sub-bands at 5 GHz, we believe that interference risk from Wi-Fi is particular to a narrow range of use cases that are unusual for Wi-Fi.
4) The Fixed Satellite Service that, in part, uses UNII-4, has little basis for concern about interference from Wi-Fi. We demonstrate why the general claims of interference risk presented by the two FSS incumbents, SES and Intelsat, are unsubstantiated.

Our conclusions are based on a rigorous technical review, and lead to the over-arching finding that there are many potential paths toward expanding Wi-Fi access at 5 GHz. We believe this analysis provides a basis for further progress toward enabling greater Wi-Fi access, and we suggest several areas for further research to this end.

2 The Need for Wi-Fi Spectrum

2.1 The 2.4 GHz Band Risks Exhaustion

A recent paper by Alderfer[5] modeled the need for additional Wi-Fi spectrum by examining how forecasted developments in traffic growth, devices, hotspots, and new standards might impact Wi-Fi capacity. This analysis concludes that growth in Wi-Fi traffic and associated trends in network density and technology efficiency are likely to lead to a shortage of Wi-Fi spectrum in the near-term, particularly with respect to the 2.4 GHz band, which is the primary Wi-Fi band today.

In particular, over the 2011-2015 period, it is estimated that Wi-Fi capacity needs will grow by approximately 1.65 times. Assuming roughly 60% average baseline Wi-Fi spectrum utilization – which understates actual utilization in dense markets and overstates it in remote areas – the 2.4 GHz band is likely to reach saturation by 2014, as shown in Figure 2-1.

[5] ROB ALDERFER, WIFI SPECTRUM: EXHAUST LOOMS (CableLabs, May 28, 2013). Available at: http://www.cablelabs.com/wireless/papers/20130528_wifi%20spectrum%20crunch_FINAL.pdf

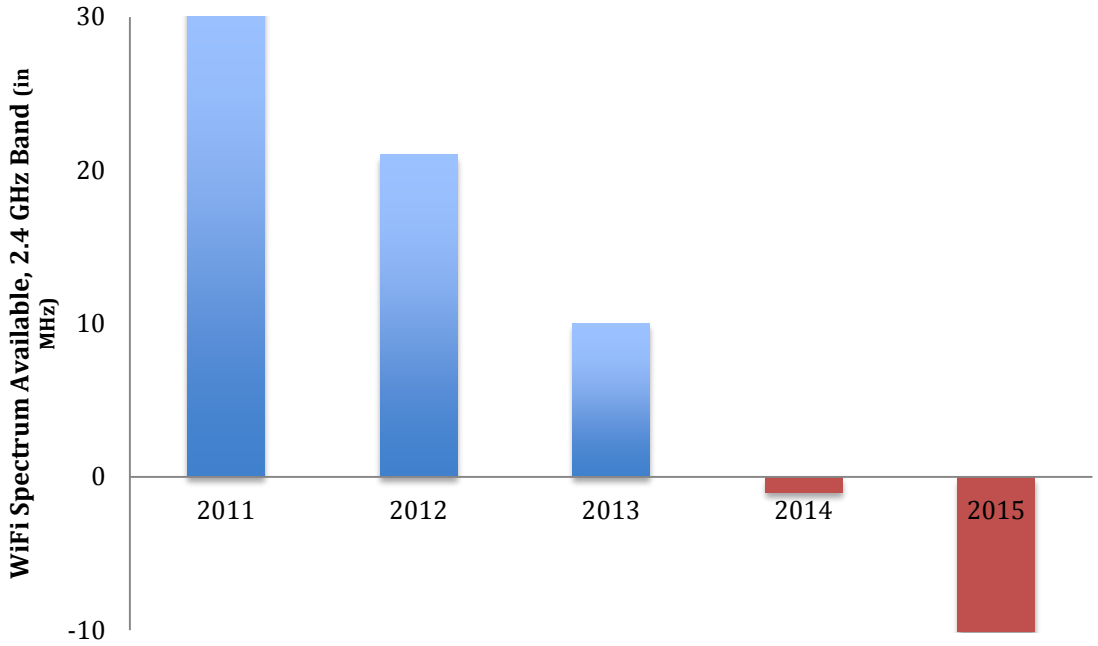

Figure 2-1: 2.4 GHz Wi-Fi Spectrum Deficit Over Time, in Megahertz, Assuming 60% Baseline Utilization

While different modeling assumptions may yield somewhat different quantitative forecasts of Wi-Fi spectrum exhaustion, it appears that the need for additional Wi-Fi spectrum is a matter of "when," not "if". Wi-Fi spectrum exhaustion is likely to have deleterious impacts to performance, as throughput slows to well below ideal as a function of increasing network congestion.

2.2 5 GHz Is Critical to Our Wi-Fi Future

In light of the likelihood of 2.4 GHz spectrum exhaustion, the importance of the 5 GHz band to the future of Wi-Fi becomes clear. However, 5 GHz Wi-Fi access is made difficult by complex rules that differ across the band, many of which are more restrictive than Wi-Fi access in the 2.4 GHz band. As seen in Figure 2-2, only 100 megahertz of the band, known as UNII-3, has access rules comparable to the 2.4 GHz band, which enable transmission at 1-Watt power, without further restrictions on usage environments or interference avoidance requirements.

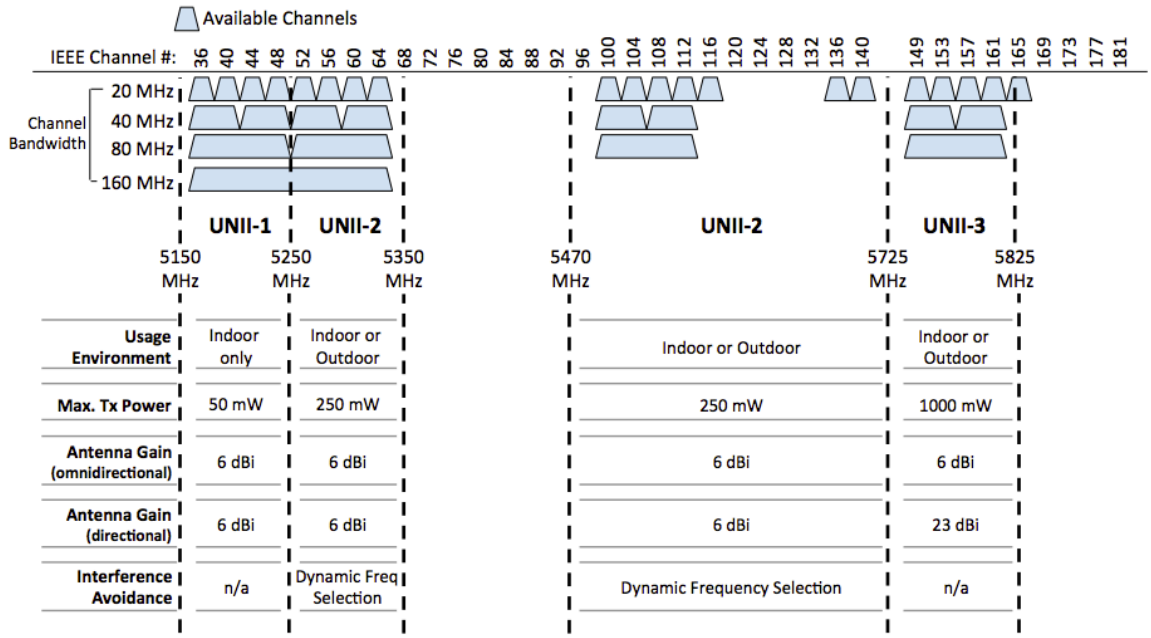

Figure 2-2: 5 GHz U-NII Band Plan Showing Regulatory Complexity

This additional 100 megahertz of Wi-Fi spectrum is likely to help mitigate the growing shortage of 2.4 GHz capacity as more devices contain radio technology that enables use of the 5 GHz band.

In particular, the latest mass-market IEEE Wi-Fi technology, 802.11ac, uses the 5 GHz band exclusively. 802.11ac features, which include higher efficiency, greater spatial streaming, and wider channel use, can enable speeds in excess of 1 Gbps over Wi-Fi. In providing wireless peak speeds in excess of what most users experience on fixed networks today, 802.11ac is a potentially revolutionary technology, and may provide significant benefits to Wi-Fi users.

However, the wide channels of 802.11ac that enable gigabit speeds also mean greater spectrum utilization. Therefore, the "burn rate" of Wi-Fi spectrum is likely to accelerate as 802.11ac technology comes online. Figure 2-3 below depicts this dynamic in the context of Alderfer's Wi-Fi capacity model, which includes the UNII-3 portion of the 5 GHz band that is most useful today for Wi-Fi because of access rules that are comparable to 2.4 GHz.

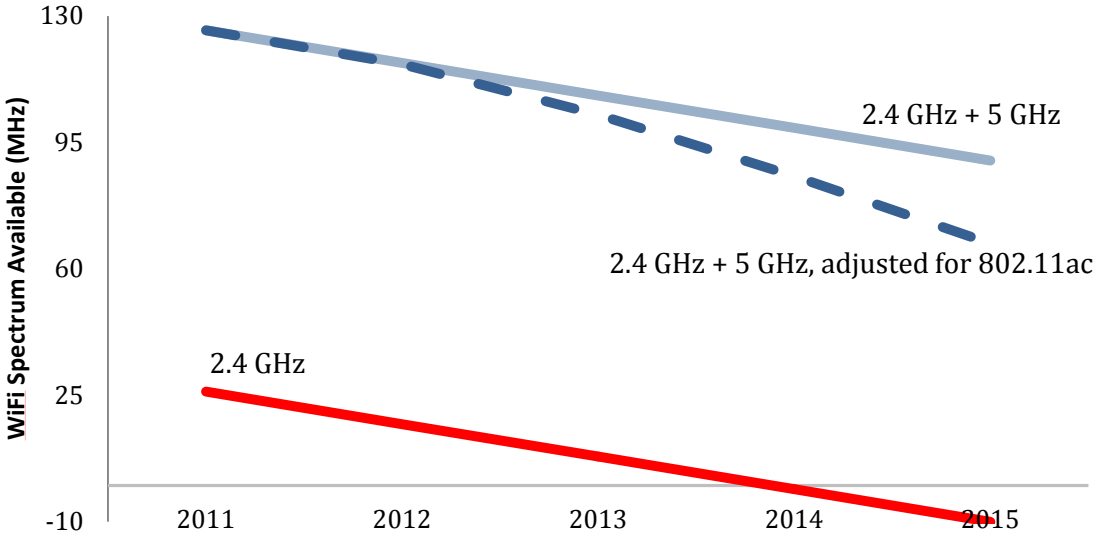

Figure 2-3: Wi-Fi Spectrum Deficit Over Time if 5 GHz UNII-3 Band is Included

Therefore, greater Wi-Fi access to the 5 GHz band on harmonized terms that complement the existing ecosystem is important to the growth of wireless broadband. Notably, full implementation of 802.11ac technology – gigabit Wi-Fi -- is not practical under current FCC rules, which would require a single 160 MHz channel to operate under different access protocols. In effect, this means that FCC rules may prevent the realization of gigabit Wi-Fi that 802.11ac promises.

The FCC's proposal to reform the 5 GHz band for greater Wi-Fi use is therefore important both to prevent Wi-Fi spectrum exhaustion and to enable full implementation of the latest technology for American consumers. As seen in Figure 2-4 below, expanded and simplified access to the 5 GHz band has the potential to yield substantial additional Wi-Fi capacity and fully enable the newest Wi-Fi technologies.

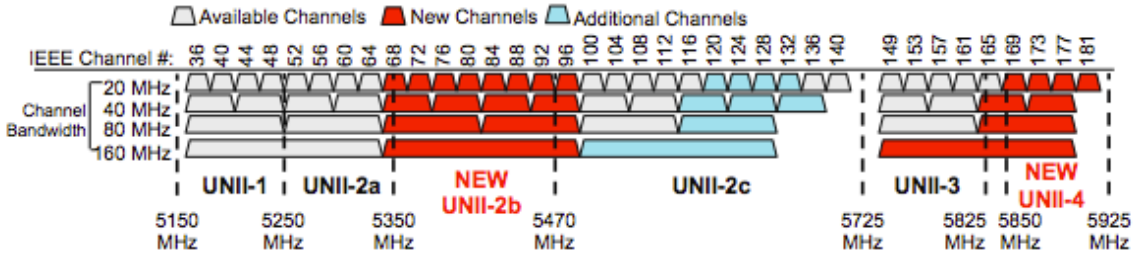

Figure 2-4: New 5 GHz Band Plan with Expanded Wi-Fi Access

3 Coexistence is Key

Given the key role that the 5 GHz band will play in meeting the surging demand for access to Wi-Fi, the Commission should ensure that these service rules are as amenable to 802.11ac deployments as possible. In order to achieve expanded, simplified, and commercially viable Wi-Fi access in the 5 GHz band, appropriate coexistence strategies will be required in order to minimize any contention risk among Wi-Fi and a number of incumbent spectrum users that populate the band.

3.1 Identifying the Incumbents

The 5 GHz band between 5150 MHz and 5925 MHz, the range proposed by the FCC for expanded and simplified Wi-Fi use, consists of a number of incumbent systems. Figure 3-1 below shows these incumbents and where they are situated in the band.

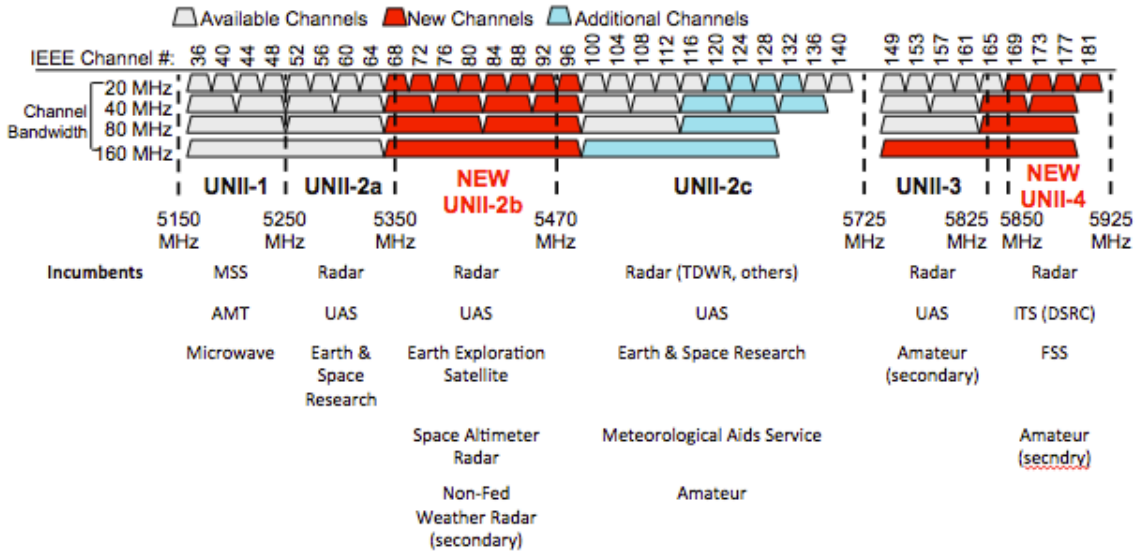

Figure 3-1: 5 GHz Wi-Fi Band and Incumbents

The characteristics of 5 GHz incumbents vary widely in terms of system architecture, usage, and Wi-Fi sharing implications. For that reason, we analyze each incumbent system independently, and focus in particular where we have sufficient information

to assess interference risks. By depicting interference risks in a straightforward manner, our goal is to lay the foundation for future work on coexistence mechanisms. The systems that we analyze in depth include:

a) Mobile Satellite Systems (MSS): Protection of what was predicted to be heavy use of UNII-1 by a large number of MSS systems led the FCC to adopt its existing conservative Wi-Fi rules in this part of the band, which include restrictions on outdoor Wi-Fi use and very low transmit power limits. The fact that MSS use of the band is far less than predicted, and that Wi-Fi has grown significantly since the FCC set these rules, has led the FCC to consider changes to the current Wi-Fi access protocols in UNII-1.
b) Intelligent Transportation System, Dedicated Short Range Communications (ITS/DSRC): A transportation communications system is planned for UNII-4. If successfully deployed in the future, it will be important to have a sharing system in place to protect ITS/DSRC operations from harmful interference. At present there is no commercial deployment of ITS/DSRC.
c) Radars: A number of radar systems exist across UNII-2, 3, and 4 which may require interference avoidance strategies. We analyze this dynamic in the context of UNII-4, but our findings are generalizable to other sub-bands.
d) Fixed Satellite Service (FSS): FSS systems in the new UNII-4 band are lightly used, enjoy substantial bandwidth above UNII-4, and consist of international directional uplink transmissions, posing a very low risk of Wi-Fi interference.

In addition to these four incumbent systems which we have prioritized for analysis, a number of other incumbent 5 GHz allocations and systems exist where sharing with Wi-Fi is likely be easier for a variety of reasons. These other systems and allocations include:

e) Aeronautical Mobile Telemetry (AMT): The government has noted the possibility that AMT systems may be moved into the UNII-1 band in the next decade from the 1755-1850 MHz band. For reasons that will be explored in this paper, this scenario remains uncertain at best.

f) Microwave Landing Systems: In setting the current conservative UNII-1 rules more than a decade ago, the FCC assumed that Microwave Landing Systems would occupy spectrum adjacent to that band. However, these systems never materialized and have now been overtaken by other technology, removing an important justification for the current UNII-1 rules.

g) Unmanned Aerial Systems (UAS): With the limited information available on UAS, the risk of Wi-Fi contention appears low due to the aerial nature of the systems and a lack of interference evidence to date.

h) Earth & Space Research: These systems,[6] which generally operate on a passive, receive-only basis across UNII-2, also appear at low risk of Wi-Fi contention due to ongoing coexistence in the current band plan.

i) Non-Federal Weather Radar: Secondary non-Federal weather radars in the new UNII-2b band should benefit from coexistence protocols explored for primary Federal radar incumbents, so non-Federal radar system coexistence is not explored in detail here.

For several of the above incumbent allocations, particularly Federal systems, limited information is publicly available. As a result, it may be the case that complete information relevant to analyzing Wi-Fi interference risk is not available. If additional information becomes available following the completion of this analysis, re-examination of interference risk and mitigation strategies may be warranted in some cases.

3.2 Analytic Framework

In this report, we endeavor to create a standardized, straightforward, and rigorous analytic framework for analyzing coexistence needs. Our framework consists of three steps.

[6] The term "earth and space research" is used in this paper to describe two separate allocations; Earth Exploration Satellite Service and Space Research. While systems of these types are different, both present a low risk of contention with Wi-Fi and we use this shorthand for brevity.

1) First, a review of available information on incumbent system architecture establishes the parameters and priorities for analysis. Incumbent 5 GHz systems with architectures that indicate low risk of Wi-Fi interference, and systems where there is inadequate public information available, do not move to the next stage of scrutiny.
2) Next, we evaluate the risk of interference between incumbent systems and Wi-Fi using the information gathered in step 1. As noted previously, our analysis may involve incomplete information about incumbent systems, and could be revised if additional system information becomes available. With respect to Wi-Fi system parameters, we generally start our analysis with a goal of simple, harmonized terms of access that allow for commercially viable Wi-Fi deployment. Specific assumptions are adapted to incumbent circumstances as required. Later sections of this report provide further detail.
3) Finally, we use the interference risks identified in step 2 to suggest areas for research on coexistence mechanisms. We do not endeavor a detailed or definitive proposal for coexistence mechanisms. Rather, we recognize that sharing etiquette requires further study.

4 Improving Wi-Fi Access to UNII-1

Wi-Fi access to the UNII-1 band is restricted to indoor use only, and is limited to 50 mW transmit power, which is 5% of the power allowed in the UNII-3 band. The utility of the band for Wi-Fi is therefore severely restricted. The FCC established these restrictions over 10 years ago in large part to protect what policymakers understood to be a budding new technology that shares the band – Mobile Satellite Services (MSS).

At the time, MSS was a new service, and both its adoption and its interference tolerance were uncertain. Therefore, the FCC adopted very conservative parameters for co-band Wi-Fi.

Since that time, Wi-Fi use has exploded, while MSS has stagnated. Wi-Fi now carries over half of all Internet data by some estimates, making it crucial to the broadband ecosystem that has become a significant national priority. Meanwhile, MSS remains a niche service used primarily for remote voice communications. The Commission has reassessed its policy toward MSS, and in enabling terrestrial use for some MSS providers, has effectively recognized that satellite service is not the highest use of the spectrum.[7]

This section explores Wi-Fi / MSS coexistence in the UNII-1 band. In general, we find that interference risk is much lower than the UNII-1 MSS incumbent system operator, Globalstar, has noted. This finding provides the basis for expanding Wi-Fi access to UNII-1.

[7] *See*, *e.g.*, FCC, IN THE MATTER OF SERVICE RULES FOR ADVANCED WIRELESS SERVICES IN THE 2000-2020 MHZ AND 2180-2200 MHZ BANDS, WT Docket 12-70, *Report and Order and Order of Proposed Modification*, Dec. 17, 2012.

4.1 Mobile Satellite System (MSS) System Architecture

Globalstar is a mobile satellite communications service that provides global voice and data services to mobile users. The system provides voice services and 9.6 kbps data access to approximately 562 thousand people across the world.[8] The service uses a constellation of 48 low earth orbit satellites that provide connectivity to users on earth through a set of 25 Globalstar gateway ground stations worldwide, with four such gateways in the US.

As shown in Figure 4-1, the system functions using four different bands.[9] The satellites communicate with mobile end-user devices via spot beams using L-band (1.6 GHz) for the uplink and S-band (2.5 GHz) for the downlink. The satellites are connected to the phone network and Internet through a terrestrial network of ground stations called gateways. These gateways use the 5096-5250 MHz band for uplink communication and the 7 GHz band for downlink communication.[10] The uplink frequencies cover the entirety of the UNII-1 allocation, as well as approximately 59 megahertz below and adjacent to the UNII-1 allocation for a total of 159 megahertz.

The communications between the satellites and mobile devices are provided through a group of 16 spot beams. These spot beams are narrow so as to provide sufficient antenna gain to effectively communicate with handheld, battery-operated mobile devices.

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[8] Globalstar FORM 10-K, March 15, 2013 ("At December 31, 2012, we served approximately 562,000 subscribers").

[9] Figure from University of California Los Angeles Computer Science Department, Satellite Networks, *available at* http://www.cs.ucla.edu/classes/winter02/cs216/l1/slides/P24_survey2.pdf.

[10] Globalstar's space stations are authorized to receive uplink transmissions from the feeder link stations in the 5096-5250 MHz band. Globalstar's feeder link earth stations in Clifton, Texas also transmit telecommand signals to the satellites in the 5091-5092 MHz band. See Globalstar Licensee LLC Application for Modification of Non-geostationary Mobile Satellite Service Space Station License, Order, 26 FCC Rcd 3948 (DA 11-520).

However, to receive signals from the gateways using 5 GHz spectrum, the spacecraft uses an antenna beamwidth that has a footprint diameter of approximately 5800 km (approximately 3600 miles). This footprint covers approximately 52° of latitude. For reference, the continental US from Key West, FL to the northern tip of Maine covers approximately 23° of latitude. This wide beamwidth on the receive antenna implies a lower receive antenna gain, which is sufficient because the gateway ground stations transmit using a 5.5 m dish pointed at the spacecraft. While this arrangement is convenient and relatively inexpensive for spacecraft implementation, it means that the satellite receiver looks down across a large geographic area, and therefore a large potential population of UNII-1 Wi-Fi access points.

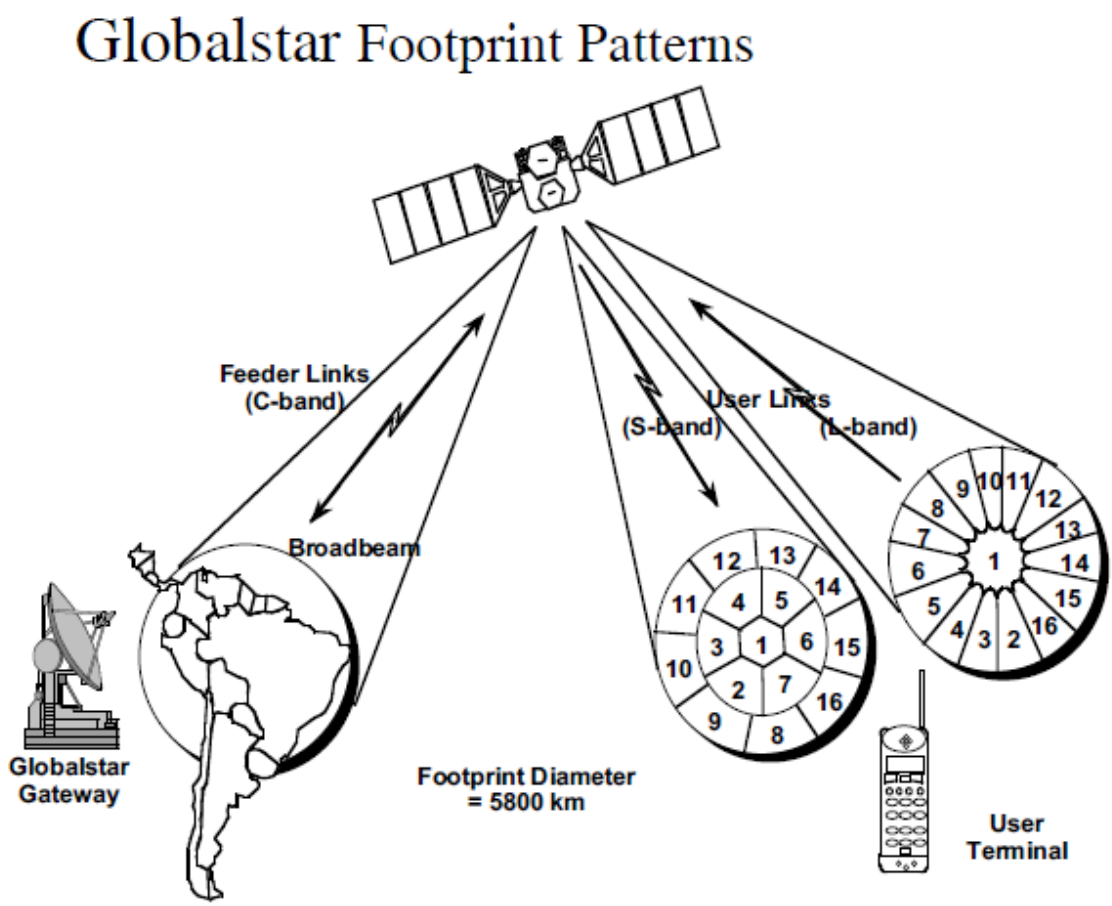

Figure 4-1: Globalstar System Diagram

The terrestrial Globalstar ground stations exist in only four locations within the US, including one in Alaska and one in Puerto Rico. These stations transmit in the UNII-1

band using a high gain antenna directed to a spacecraft, so the interference potential to terrestrial UNII-1 Wi-Fi devices should be minimal and extremely localized.

The Globalstar spacecraft can be considered, despite its sophisticated phased array technology, as a "bent pipe" satellite in the traditional sense. The traditional transponder-based satellite has a set of frequency translating amplifiers (transponders) that provide energy out proportional to the energy in, along with a conversion to the downlink frequency. The Globalstar UNII-1 uplink serves traffic destined for mobile terminals in the 2.5 GHz band. The satellite receives signals destined for mobile terminals and passes the signal to the appropriate downlink beam within the 2483.5 – 2500 MHz band. In this way, the satellite serves as a bent pipe; there is no on board processing of the signals nor is there any demodulation and regeneration.

Although Globalstar has been granted authority to deploy an Ancillary Terrestrial Component (ATC), enabling the MSS provider to augment satellite coverage using terrestrial network of cell phone towers, ATC is not yet deployed. If deployed, ATC expected to use the L-band and S-band frequencies. ATC operations therefore should not interfere with Wi-Fi. Some uplink traffic to the satellite would presumably continue to be transmitted from the Globalstar gateway ground stations using the UNII-1 band.

4.2 Contention Risk

One means of conceiving of the interference risk to MSS in UNII-1 is by examining the aggregate power of Wi-Fi access points as seen by the satellite receiver in space. This approach is a 'single link' interference analysis, in that it only considers the 'noise' at the satellite uplink receiver in space. This is the approach to interference analysis taken by Globalstar in its recent comments to the FCC.[11]

A more appropriate means of approaching interference risk would examine the end-to-end system performance, rather than conducting only a narrow 'single link'

[11] *See* Comments of Globalstar in ET Docket 13-49, May 29, 2013.

analysis. Though Globalstar's downlink operates in a separate band from 5 GHz Wi-Fi, this more holistic approach is a superior framework because Globalstar's satellites perform only 'bent pipe' functionality. That is, there is no signal processing at the satellite; the satellites simply convert the 5.2 GHz feeder link signal to the 2.5 GHz downlink band for reception by end-user devices (e.g., satellite phones).

Our goal in this section is to explore how real the risk of interference is, and if it is real, at what levels. To do so, we critique Globalstar's 'single link' analysis as overly conservative, and conduct a more appropriate 'whole system' analysis. We find that, in an accurate manifestation of the 'single link' approach, Wi-Fi use can be expanded much more broadly than estimated under the equivalent Globalstar findings. In addition, on a 'whole system' basis, we find that there is very little to no risk to MSS from expanding Wi-Fi access. This 'whole system' analysis is a more appropriate measure of risk than the 'single link' approach, which is based on a generic ITU noise floor standard that does not account for Globalstar's system functionality.

Interference risk is not proximate to the Earth stations – of which there are few in the US, and which are uplink only. Nor is the risk to ATC, which is not yet deployed, and would operate in different bands.

4.2.1 'Single Link' Interference Analysis

The technical analysis submitted by Globalstar in the 5 GHz proceeding is an inaccurate accounting of the interference environment, analyzing the effect of expanded Wi-Fi access under conditions that are not realistic.[12] Their results are shown below in Figure 4-2. They conclude, for example, that if UNII-1 power levels are increased to UNII-3 levels and are permitted outdoors, a mere 201 access points operating in the US would cause interference to their systems.[13]

[12] *See* Comments of Globalstar in ET Docket 13-49, May 29, 2013.

[13] *Id.* at App. 1, page 3.

		Current U-NII-1 Conditions	U-NII-1 Levels with Outdoor Operation	Power Increase to U-NII-2 Levels Indoors	Power Increase to U-NII-2 Levels Outdoors	Power Increase to U-NII-3 Levels Outdoors
		5150-5250 MHz	515-5250 MHz	5150-5250 MHz	5150-5250 MHz	5150-5250 MHz
Globalstar System Characteristics						
Satellite Altitude (km)		1414	1414	1414	1414	1414
Spreading Loss (dB)		134.0	134.0	134.0	134.0	134.0
Comparisonof PFD with ΔT/T						
T of Globalstar (K)		509.3	509.3	509.3	509.3	509.3
Log (K)		27.1	27.1	27.1	27.1	27.1
Boltzmann's Const.(dBW/K/Hz)		-228.6	-228.6	-228.6	-228.6	-228.6
No of Globalstar Spacecraft (S/C) (dBW/Hz)		-201.5	-201.5	-201.5	-201.5	-201.5
Frequency (MHz)		5200.0	5200.0	5200.0	5200.0	5200.0
Area of 0dB Gain Ant. (m^2)		-35.8	-35.8	-35.8	-35.8	-35.8
Rx Lvl for 1% Delta T/T (dBW/MHz)		-161.5	-161.5	-161.5	-161.5	-161.5
Rx Lvl for -124 dBW/MHz/m^2 PFD		-159.8	-159.8	-159.8	-159.8	-159.8
Rec. ITU-R S.1426 PFD =>ΔT/T		1.50	1.50	1.50	1.50	1.50
# of Compatible U-NII Users						
U-NII EIRP Density 802.11a (dBW/MHz)		-20.0	-20.0	-13.0	-13.0	-7.0
Indoor/Outdoor Attenuation (dB)		17.0	0.0	17.0	0.0	0.0
U-NII PFD 802.11a (dBW/MHz/m^2)		-171.0	-154.0	-164.0	-147.0	-141.0
Rec. ITU-R S.1426 PFD (dBW/MHz/m^2)		-124.0	-124.0	-124.0	-124.0	-124.0
Allowable number 802.11a U-NII Users						
per Chan in Sat Receive Beam		50131	1000	10003	200	50
Number of U-NII Chans		4	4	4	4	4
Total U-NII Users		200525	4001	40010	798	201
Access Points						
# of Access Points in USA	140000					
# 802.11a Equipped	70000	70000	70000	70000	70000	70000
Access Point per Chan EIRP (dBW)		-7	-7	0	0	6
802.11 Chans Avail		4	4	4	4	4
# of Access Points per Chan		17500	17500	17500	17500	17500
Bandwidth of U-NII Chan (MHz)		20	20	20	20	20
Indoor/Outdoor Attenuation (dB)		17	0	17	0	0
Access Pt EIRP/Chan Indoor (dBW)		18.4	35.4	25.4	42.4	48.4
PFD @ S/C (dBW/MHz/m^2)		-128.6	-111.6	-121.6	-104.6	-98.6
Path Loss @ 1414km (dB)		-169.8	-169.8	-169.8	-169.8	-169.8
Pwr @ S/C/20MHz Chan (dBW)		-151.3	-134.3	-144.3	-127.3	-121.3
Pwr @ S/C/1.23 MHz Chan (dBW)		-163.5	-146.5	-156.5	-139.5	-133.5
Delta T/T		0.5	26.2	2.6	131.2	522.2

Figure 4-2: Globalstar 5 GHz Interference Analysis

For a variety of reasons, their analysis is faulty. Among other errors, Globalstar fails to account for the lack of Wi-Fi power radiation up toward the satellite, they do not incorporate path and clutter loss of Wi-Fi signals on the ground, they do not account for 'duty cycles' of Wi-Fi, and make other assumptions leading to undue concern over expanded Wi-Fi access.

Analysis that better accounts for the true RF environment would suggest that Globalstar overstates interference risk significantly, even under this narrow 'single

link' analytic framework. In the rest of this subsection, we demonstrate why that is the case through review of Globalstar's analytic errors.

Error 1: Globalstar uses a faulty Wi-Fi power radiation (gain) assumption.

Consider the influence of directional power radiation and the angle of the MSS satellite. Indoor broadband units typically have antenna that exhibit a radiation pattern that is roughly omni-directional in nature. That is to say, these antennas tend to distribute energy around a 360° circle but do not generally have gain (they do not direct power) in an upward direction. An example of this sort of antenna pattern is shown in Figure 4-3.

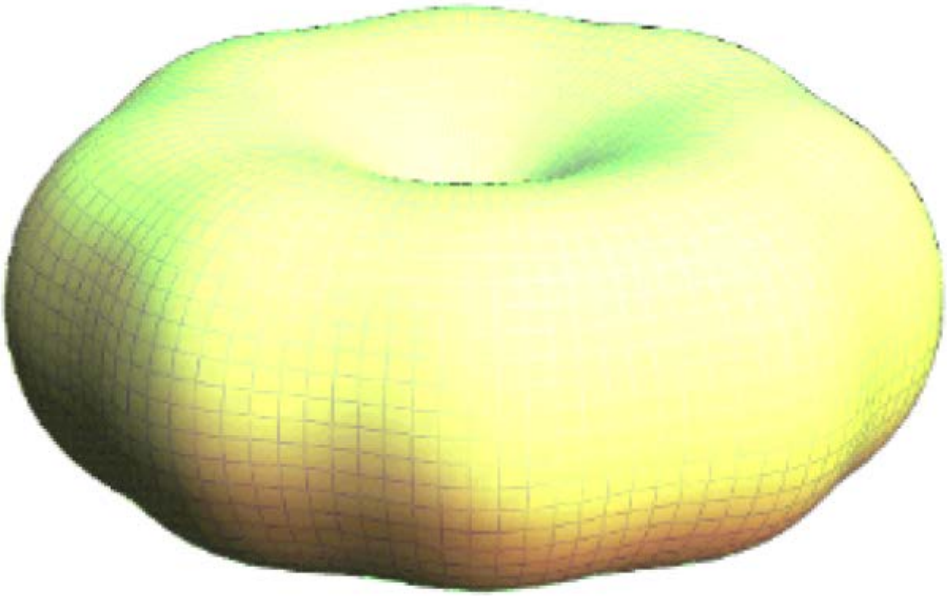

Figure 4-3: 3-D Rendering of an Omni-directional Antenna Pattern

For outdoor deployments of Wi-Fi systems, omni-directional antennas are common. Outdoor hotspot deployments sometimes use directional antennas that have gain in one prominent direction. Directional antennas in the 5 GHz band can have gains as large as 16 dBi for 90° sector antennas. An example of a directional antenna pattern is shown in Figure 4-4. Omni-directional antennas, such as commonly mounted on streetlights for muni-Wi-Fi systems, might have 6 dBi of gain.

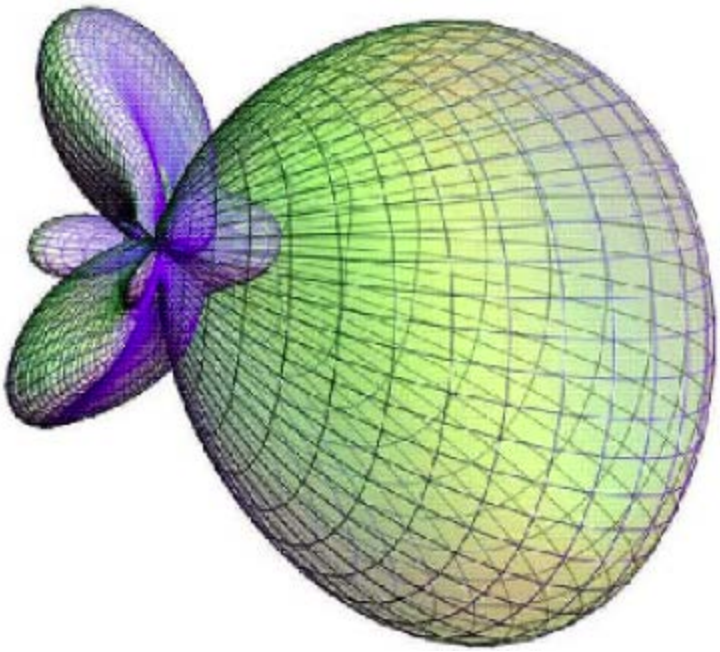

Figure 4-4: 3-D Rendering of a Directional Antenna Pattern

For all of these antennas, indoor or outdoor, directional or omni-directional, it is important to consider that there is very little gain in an upward direction, as seen in Figures 4-3 and 4-4. That is to say, these antennas direct very little power in the skyward direction, as their purpose is to serve terrestrial users that are near to the access point. This is an important point, since Globalstar's analysis assumes no Wi-Fi signal diminishment, and a satellite angle at zenith, or directly overhead.

In effect, Globalstar's assumptions seem to envision Wi-Fi signals pointed directly up at the satellite when it is at its closest point. Further, their assumptions imply that the satellite will be directly overhead every access point in the United States, which is plainly impossible.

In reality, a typical 5 GHz outdoor omni-directional antenna might have 10 dB less gain at a 30 degree angle above the horizon and at least 15 dB less gain at the zenith. A better approach would be to assume that the EIRP from a ground based UNII-1 access point will be diminished by 15 dB at the zenith, by 6 dB for a satellite at a 30° elevation angle, and by 3 dB for a satellite at a 10° elevation angle.

Errors 2 and 3: Globalstar uses a faulty satellite elevation angle assumption, and fails to properly account for Wi-Fi signal attenuation.

LEO satellites are rarely observed to go directly overhead for any given user in the US. One study demonstrated that 88% of the time a Globalstar satellite will be observed between 30° to 60° elevation angle above the horizon at Earth latitude of 41.9° (the approximate latitude of Denver, CO.).[14] The same study showed that at that latitude the likelihood a Globalstar satellite would be between 80° to 90° (zenith) is less than one half of one percent. Despite this fact, Globalstar bases its entire analysis on the assumption that satellites will be at a 90 degree elevation angle at all times.

Additionally, most suburban and urban areas – the areas where Wi-Fi is primarily deployed - will not allow a direct line-of-site to a satellite at an elevation angle in the 30° to 60° range because of scattering and absorption of energy by buildings and vegetation. As a result, clutter losses for satellite elevation angles less than zenith should be incorporated into the analysis; for example, a 30° elevation angle may entail 3 dB loss, and an elevation angle of 10° may result in 5 dB loss. Globalstar fails entirely to account for such losses.

Elevation angles below zenith result in longer path lengths between the transmitter and the satellite receiver. Longer path lengths result in considerably greater path loss for Wi-Fi signals, meaning that interference risk to MSS is lower. The effects of different elevation angle distances on spreading loss values are significant and shown in Figure 4-5. Again, Globalstar does not account for these Wi-Fi signal losses.

satellite altitude	1414.00	km		
average elevation angle to satellite	90	30	10	degree
distance to satellite	1414	2320.8	3472.6	km
spreading loss	134.0	138.3	141.8	dB

Figure 4-5: Satellite Distance as a Function of Elevation Angle

[14] G.E. Corazza & F. Vatalaro, *A statistical model for land mobile satellite channels and its application to nongeostationary orbit systems*, 43 IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY 738, 742, Aug 1994.

Error 4: Globalstar relies on an interference metric that may be outdated and does not fully account for actual system capabilities.

Globalstar's single-link analysis is based on ITU Recommendations for interference limits.[15] That recommendation defines the interference limit, or maximum noise floor at the satellite receiver, as a Power Flux Density (PFD) at the satellite antenna of -124 dB(W/(m^2 • 1 MHz)).

It is important to note that this PFD was designed in the 1990s, and was intended to enable different satellite architectures in the 5 GHz band. The noise floor at the satellite is a relevant interference metric if the satellite is performing on-board processing; however, Globalstar's system is a 'bent pipe', with no such processing. At the time of the ITU recommendation, there was no way of knowing that there would be only one satellite operator in 5 GHz, and that a 'bent pipe' architecture would prevail.

In addition, the market had not yet developed at the time of the ITU recommendation, and technology advances since that time likely make the standard overly conservative. If, for example, Globalstar now has a lower American user density than originally assumed pre-launch, the system may be more tolerant of interference. Advances in forward error correction coding, which would provide equivalent perceived voice call quality even with a slight increase in overall frame error rate, could also mean this ITU recommendation is no longer an accurate measure of the level of interference that satellites can tolerate. There may also be improvements to link budget margins with Globalstar's launch of second-generation satellites as a function of technology improvements. While the ITU PFD limit provides conservative guidance, it would be more appropriate to evaluate interference risks based on actual system capabilities and market realities.

Error 5: Globalstar fails to account for Wi-Fi duty cycles.

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15 *See* ITU Radiocommunication Sector, *Aggregate power flux density limits at the FSS satellite orbit for radio local area network transmitters operating in the 5150-5250 MHz band sharing frequencies with the FSS*, ITU-R S.1426.

The interference study performed by satellite operators in 1996 assumed a Wi-Fi access point duty cycle of 10% (i.e. transmissions occurring for a maximum of 1/10 of the time).[16] This duty cycle is not accounted for in Globalstar's analysis. The effect of this error is significant. If the population of UNII-1 access points is independent and evenly distributed, then the equivalent number of full duty cycle access points is ten times greater than what Globalstar would conclude from this error alone.

Error 6: Globalstar fails to account for UNII-1 channelization.

There are four 20 MHz channels currently defined by the IEEE in the UNII-1 band. Thus the number of devices can be multiplied by four before reaching a -124 dB(W/(m^2 • 1 MHz)) PFD at the satellite; Globalstar fails to make this adjustment.

Contrary to Globalstar's results, this critique demonstrates that outdoor UNII-1 access points pose a far less significant risk of interference, even under a narrow 'single link' interference framework.

It is worth noting that even the numbers in a 'single link' analysis could be conservatively misconstrued. For example, if UNII-1 rules become harmonized with UNII-3, access points using UNII-1 will never all transmit at 1W at the same time. Many access points deployed at UNII-3 today use a lower power level than allowed by the FCC. The implication of this observation is that any increased allowance for Wi-Fi in UNII-1 should not simply be capped at the number of access points at the level generated by such a methodology. Real-world deployment will occur both indoor and outdoor, at a variety of power levels, even if UNII-1 is harmonized with UNII-3.

It is also important to keep in mind that Wi-Fi access points will be able to select channels from across the 5 GHz UNII band, not only UNII-1. Therefore, many more Wi-Fi access points can be deployed without risk to UNII-1 systems, given the ability to select different channels.

[16] Comments of MSS Satellite Joint Commenters in ET Docket 96-102, 1996, at 6.

Further, the results from such an analysis represent access points only; Wi-Fi devices can be deployed much more broadly, since most transmit at a lower power level, and since, in general, only one is communicating with an access point at any given moment in time.

4.2.2 'Whole System' Interference Analysis

While it appears clear that Wi-Fi use can be expanded significantly without causing a meaningful change in the noise floor at the satellite receiver, considering interference risk based on this 'single link' analysis is an inferior methodology in this context. A more appropriate approach to analyzing interference risk is to look at the entire system, from the uplink Gateway to the satellite, and from the satellite to the end-user devices. This approach is preferable because Globalstar's satellites simply pass through a signal, converting it from the 5.2 GHz band on the uplink to the 2.5 GHz band on the downlink. Therefore, the true test of system risk is end-user performance.

In the following paragraphs we explore how expanded Wi-Fi use may impact Globalstar's end users, and we find that the limiting link in the system is the downlink, not the 5.2 GHz uplink. As such, Wi-Fi use can be significantly expanded in UNII-1 without harm to Globalstar system performance.

As noted previously, the Globalstar spacecraft can be considered, despite its sophisticated phased array technology, as a "bent pipe" satellite in the traditional sense. The traditional transponder-based satellite has a set of frequency translating amplifiers (transponders) that provide energy out proportional to the energy in, along with a conversion to the downlink frequency. The Globalstar UNII-1 uplink serves traffic destined for mobile terminals in the 2.5 GHz band. The satellite receives signals destined for mobile terminal and passes the signal to the appropriate downlink beam and rebroadcasts that signal within the 2483.5 – 2500 MHz band. There is no on board processing of signals nor is there any demodulation and regeneration.

This architecture provides flexibility by minimizing complexity in orbit, and is typical of a majority of satellites in service today. The satellite provides some gain of the signal but, like any amplifier, it adds noise to the signal before retransmission. The relevant metric for system performance is the carrier-to-noise ratio, calculated as C/N, where C is the carrier signal and N is the noise level. At the final receiver destination (in this case, the mobile terminal), the ratio is based on a combination of the uplink C/N as it passes through the satellite, $\left(C/N\right)_{UP}$, and the C/N ratio of the downlink as it arrives at the final receiver (the mobile terminal), $\left(C/N\right)_{DN}$. A common satellite analysis technique is to determine the $\left(C/N\right)_{UP}$ ratio to the satellite and to determine the $\left(C/N\right)_{DN}$ ratio for the space to earth link and to combine these to determine the total end-to-end system carrier to noise ratio, $\left(C/N\right)_{O}$. The system $\left(C/N\right)_{O}$ can be derived by combining the uplink and downlink C/N ratios using the following formula:[17]

$$C/N_O = \frac{1}{\left[\frac{1}{\left(C/N_{UP}\right)} + \frac{1}{\left(C/N_{DN}\right)}\right]} \qquad (1)$$

We can apply this end-to-end interference analysis to the Globalstar system using operating parameters published in a journal by Globalstar itself. [18] In doing so, we find that the limiting link in the Globalstar system is the downlink, operating at the 2.5 GHz band. 'Noise' (Wi-Fi signals) can be added to the uplink in the 5.2 GHz band without affecting the overall performance of the system. This is because the uplink

[17] Pratt, T; Bostian, C.; Allnutt, J.; Chapter 4, *Satellite Communications*, 2nd ed., John Wiley & Sons, 2003.

[18] Hirshfield, E., "The Globalstar System", Applied Microwave & Wireless, Summer 1995.

has a large EIRP from the Gateway, which incorporates a high-powered amplifier in combination with a 5.5 m dish.

The following table shows the differences in uplink vs. downlink C/N for a 2400 bps data rate to the Globalstar handset, using operating assumptions from Globalstar. Again, these assumptions are likely to be conservative, relative to real-world deployment. For example, the analysis assumes that the satellite is at zenith, or directly overhead; but as we have noted, there is more likely to be a horizon angle in a real-world scenario, which increases the distance to the satellite, creating greater signal loss. Nevertheless, Figure 4-9 shows that the uplink signal is much stronger than the downlink signal, indicating that the limiting link in the system is the downlink.

Parameter	Forward Link		Return Link		Units
	Satellite to User Terminal	Gateway to Satellite	User Terminal to Satellite	Satellite to Gateway	
Nominal Frequency	2.5	5	1.6	7	GHz
EIRP/User (nadir, clear)	1.1	36.4	-14.3	-33.3	dBW
Space Loss (nadir, clear)	163.4	169.7	159.6	172.3	dB
Other Factors	1.40	7.90	2.10	1.60	dB
G/T (hand held)	-26	-29.6	-14.25	27.5	dB/K
Eb/No*	5.1	24	4.5	15.1	dB
Average Data Rate	2400	2400	2400	2400	bps
Diversity Benefit			2.2		dB
Composite Eb/No	5		6.3		dB

* Satellite to U.T. & Satellite to Gateway link Eb/No are combined results of both up and down paths.

Figure 4-9: Globalstar System Link Budget (from Globalstar)

The original table from Globalstar does not show the uplink and downlink C/N, so we have reproduced it in Figure 4-10 below. The conversion from C/N to E_B/N_O is

a function of the CDMA processing gain. Based on the average data rate of 2400 bps, the processing gain is approximately 27.1 dB.

Gateway to Satellite			Satellite to User Terminal		
UL freq.	5.20E+09		DL freq.	2.49E+09	Hz
lambda	0.0577		lamda	0.1203	m
Gateway EIRP	36.4		Sat EIRP	1.1	dBw
other losses	7.9		other losses	1.4	dB
zenith path loss	-169.78		nadir path loss	-163.39	dB
G/T	-29.6		G/T	-26	dB
C/N	-3.17		C/N	-21.98	dB
Eb/No	23.92		Eb/No	5.11	dB

Figure 4-10: Globalstar System Link Budget with Carrier to Noise Ratio Values

Based on Globalstar's analysis, the uplink signal $\left(C/N\right)_{UP}$ is -3.17 dB while the downlink $\left(C/N\right)_{DN}$ is almost -22 dB. This is a difference of approximately 18.8 dB or a factor 76. That is, the uplink $\left(C/N\right)_{UP}$ signal is approximately 76 times stronger than the downlink $\left(C/N\right)_{DN}$; therefore, the limiting link in the Globalstar system is the downlink.

Based on the above values of $\left(C/N\right)_{UP}$ and $\left(C/N\right)_{DN}$, we can determine the overall system $\left(C/N\right)_{O}$ using equation (1) to be:

$$\left(C/N\right)_{O} = \frac{1}{\left[\frac{1}{(0.4817)} + \frac{1}{(0.006335)}\right]}$$

$$\left(C/N\right)_{O} = 0.006252 \text{ or } -22.04 \text{ dB}$$

It can be observed that the overall system $\left(C/N\right)_O$ of -22.04 dB is approximately equal to the downlink $\left(C/N\right)_{DN}$ of -21.98 dB. This is because the system $\left(C/N\right)_O$ is dominated by the small $\left(C/N\right)_{DN}$. This observation verifies that significant noise can be added to the uplink without affecting overall system performance.

Given that the uplink $\left(C/N\right)_{UP}$ has margin (allowance for additional noise), it is possible to apply additional noise to the uplink without severely impacting the overall system $\left(C/N\right)_O$. To illustrate this, let us reduce $\left(C/N\right)_{UP}$ by 4.45 dB. That is, let us postulate the addition of noise on the uplink from UNII-1 devices sufficient to reduce $\left(C/N\right)_{UP}$ from a nominal -3.17 dB to -7.62 dB. From equation (1) we find the change in overall system $\left(C/N\right)_O$ as:

$$\left(C/N\right)_O = \frac{1}{\left[\frac{1}{(0.1729)} + \frac{1}{(0.006335)}\right]}$$

$$\left(C/N\right)_O = 0.006111 \text{ or } -22.1388 \text{ dB}$$

We see that a 4.45 dB increase in the noise level at the satellite changed the overall system $\left(C/N\right)_O$ by only 0.1 dB, from -22.04 dB to -22.14 dB. A 0.1 dB change in the overall system performance should be immaterial, and likely imperceptible, to Globalstar's system operation.

The 4.45 dB increase in uplink noise, while immaterial to Globalstar, permits a significant increase in Wi-Fi usage in the UNII-1 band. To illustrate this, we can calculate how many additional Wi-Fi access points would be required, at different operating parameters, to raise noise by 4.45 dB at the Globalstar satellite receiver. Figure 4-11 below shows an analysis to derive the number of UNII-1 devices that

would need to be deployed to cause the 0.1 dB decrease in the overall system $\left(C/N\right)_O$. The analysis uses similar Wi-Fi system parameters to the approach we described in our critique of Globalstar's 'single link' analysis, considering different output power levels and indoor versus outdoor operation.

90 deg. Elevation angle	current UNII-1	current UNII-1, outdoors	at UNII-2, indoors	at UNII-2, outdoors	at UNII-3, indoors	at UNII-3, outdoors	
output power/20MHz	23.0	23.0	30.0	26.0	36.0	36.0	dBm
	-7.0	-7.0	0.0	-4.0	6.0	6.0	dBW
	0.0100	0.0100	0.0500	0.0199	0.1991	0.1991	W/MHz
power density	-20.0	-20.0	-13.0	-17.0	-7.0	-7.0	dBW/MHz
building penetration loss	17.0	0.0	17.0	0.0	17.0	0.0	
off axis antenna gain reduction	N/A	15.0	N/A	15.0	N/A	15.0	dB
average clutter loss at 90 deg.	0.0	0.0	0.0	0.0	0.0	0.0	
Pr from single UNII-1 device	-206.8	-204.8	-199.8	-201.8	-193.8	-191.8	dBW/MHz
Pr from single UNII-1 device	-205.9	-203.9	-198.9	-200.9	-192.9	-190.9	dBW/1.25MHz
new N sys	-136.2	-136.2	-136.2	-136.2	-136.2	-136.2	dBW/1.25MHz
delta	69.7	67.7	62.7	64.7	56.7	54.7	dB
number of devices full duty	9,349,120	5,898,896	1,865,395	2,956,451	468,566	295,645	
number of devices 10% duty cycle	93,491,197	58,988,957	18,653,946	29,564,512	4,685,659	2,956,451	
number 1.25MHz channels	65	65	65	65	65	65	
total number UNII-1 devices	6,086,666,468	3,840,426,911	1,214,449,623	1,924,772,940	305,055,953	192,477,294	

Figure 4-11: Hundreds of Millions, perhaps Billions, of Wi-Fi Access Points Can Be Deployed In UNII-1 Without Risk to MSS Systems[19]

As seen above, the number of UNII-1 access point that could be deployed under this hypothetical 0.1 dB decrease in overall $\left(C/N\right)_O$ is much larger than Globalstar's narrow 'single link' analysis. Even if Wi-Fi operating parameters in UNII-1 look similar to UNII-3, over 190 million access points could be deployed while increasing the system carrier to noise ration of only 0.1 dB.

[19] The technical assumptions used in this analysis to reflect Wi-Fi use are as described in our critique of Globalstar's 'single link' analysis. We have added a new factor to reflect the end-user satellite users, described in the table as "new N sys". The "new N sys" is -136.2 dBW is taken be within a 1.25 megahertz bandwidth, which is based on the commercial CDMA bandwidth that Globalstar uses as an air interface. The -136.2 dBW value is 4.45 dB larger than the nominal Globalstar noise level of -140.6 dBW[19]. Note that the Globalstar link calculation is for a single user terminal operating within a given 1.25 megahertz bandwidth. The UNII-1 band of interest is 80 megahertz wide, which would permit 65 possible 1.25 megahertz user terminals to operate. For this reason, we multiply by 65 to determine the final number of UNII-1 devices that can operate simultaneously (assuming, as previously, a 10% duty cycle for Wi-Fi).

Given that 0.1 dB is an extremely small factor, it is likely that an even greater number of access points could be deployed at UNII-3 levels without affecting Globalstar's MSS operations.

Further, as we have noted, real-world deployment of Wi-Fi would include indoor hotspots and transmit power levels well below the upper bounds set by FCC rule. Therefore, harmonization of UNII-1 Wi-Fi rules with those in place for UNII-3 could enable hundreds of millions, and perhaps billions, of Wi-Fi access points to be deployed without impacting MSS. And the number of client devices that can be deployed without risk to incumbent systems is even greater, as noted previously. In effect, there is very little to no real-world risk to MSS from expanding Wi-Fi access in UNII-1.

While this approach to interference risk analysis clearly demonstrates that there is little to no risk to Globalstar's system from additional Wi-Fi use of the band, there are some points of uncertainty. For example, the Globalstar satellite has downlink power control (at 2.5 GHz) that is based on the power flux density received at the uplink (at 5.2 GHz). An increase of the PFD at the input by as much as 4.45 dB may influence the downlink power control. That said, there should be some level of input noise power to the frontend that can be tolerated without disrupting or degrading normal satellite service. It is conceivable that the on-board power control parameters could be modified from the ground. Also, there may be maximum input restrictions on the Globalstar uplink transponders that need to be considered. In some transponders, if there is too much input energy, amplifiers can be driven into a non-linear operating region, which may corrupt satellite operation. Despite these uncertainties, this end-to-end system analysis has shown that the uplink $\left(C/N\right)_{UP}$, which is co-band with Wi-Fi, has suitable margin to permit sharing of the spectrum, since the system bottleneck is on the downlink, which operates in a different band.

4.3 UNII-1 Conclusion

Current restrictions on Wi-Fi use of UNII-1 were designed many years ago to protect nascent MSS systems. Such systems have not flourished, while Wi-Fi has grown to become critical to wireless broadband, calling into question the wisdom of the current protections.

In analyzing the interference risk to MSS from Wi-Fi, we believe that substantial expansion of Wi-Fi would not result in harm to MSS. A holistic approach to analyzing interference risk suggests that no special protections are likely to be required for MSS.

An objective policy focused on the public interest would therefor pose minimal, if any, restrictions on Wi-Fi use. If special interference protections are explored for MSS, they should be based on realistic technical analysis and actual Wi-Fi deployment.

5 Expanding Wi-Fi Access to UNII-4

The Commission has proposed to open up the 5.85-5.925 GHz band, known as UNII-4, to Wi-Fi on the same terms as the existing UNII-3 band.[20] We believe it is possible to open UNII-4 spectrum for Wi-Fi with service rules harmonized with UNII-3 through commercially viable coexistence mechanisms.

Uniform, harmonized service rules will allow consumers to take full advantage of the 802.11ac standard, which uses wider channels to reach gigabit Wi-Fi speeds. Harmonizing access rules across 5.725-5.925 GHz would allow devices to operate over 200 megahertz of spectrum, enabling a full 160 megahertz channel and gigabit Wi-Fi throughput.[21] Ideally this will be done under commercially amenable rules similar to those in the UNII-3 band,[22] maximizing the benefits of this new technology.

In this section we analyze the incumbent allocations in UNII-4: Intelligent Transportation Systems using Dedicated Short Range Communications (ITS/DSRC), Federal Radars, and the Fixed Satellite Service (FSS).

5.1 Intelligent Transportation Systems / Dedicated Short Range Communications (ITS/DSRC)

DSRC is envisioned as a vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) radio technology that can make transportation safer and more efficient by communicating information about traffic and road conditions as well as providing crash-avoidance messages in-car.

[20] FCC, REVISION OF PART 15 OF THE COMMISSION'S RULES TO PERMIT UNLICENSED NATIONAL INFORMATION INFRASTRUCTURE (U-NII) DEVICES IN THE 5 GHZ BAND, *Notice of Proposed Rulemaking*, ET Docket 13-49, ¶ 97 (Feb. 20, 2013) (5 GHz NPRM).

[21] Cisco, 802.11AC: THE FIFTH GENERATION OF WI-FI, TECHNICAL WHITE PAPER, 3 (Aug. 2012), *available at* http://www.cisco.com/en/US/prod/collateral/wireless/ps5678/ps11983/white_paper_c11-713103.html#wp9000344 (Cisco 802.11ac Paper).

[22] UNII-3 access rules resemble those in place today in the 2.4 GHz Wi-Fi band.

However, it is not clear that DSRC will achieve the ubiquity required for its viability. Due to its nature as a 'connected vehicle' technology, ITS requires a critical mass of DSRC enabled vehicles before the service is valuable. It is unclear, given the competition from other technologies that serve similar purposes, whether ITS can reach the adoption rates necessary. Although the FCC granted DSRC spectrum over a decade ago, the technology is still in the research and development phase, with major changes still being made in the last three years.

Furthermore, commercially available alternative technologies duplicate many functions of DSRC, such as mapping and routing solutions. This calls into question the proper scope of the DSRC project. Those services that are not yet duplicated by other technology – such as real-time crash avoidance messaging – will not require the full 75 megahertz spectrum allocation that DSRC enjoys today. Further, these services may be better provided by the existing ITS spectrum allocation in the 902-928 MHz band due to its more favorable propagation.

Even if ITS does see wide adoption in its current form in UNII-4, we believe Wi-Fi should be able to coexist with ITS. Proponents of the project significantly overstate the risk of interference by assuming that *any* interference would be harmful interference that would significantly degrade ITS service. However, there are already numerous sources of interference, including transmissions from other ITS vehicles, that affect the transmission of basic safety messages in the system. Any interference risk to ITS from Wi-Fi would be on the margin, in combination with other existing environmental noise factors.

There is good reason to believe sharing between ITS/DSRC and Wi-Fi is possible, as the specifications for both technologies are under active development by the same standards body, the IEEE. For that reason, the Commission should enable industry experts to develop coexistence protocols and expand Wi-Fi access to UNII-4. We explore these issues in more detail in this section.

5.1.1 System Architecture and Background

Congress first created the ITS program in 1991. That same year, ITS America was founded as a Federal Advisory Committee to the Department of Transportation.[23] Eight years later, in 1999, the Commission allocated the 5.9 GHz band for DSRC-based ITS applications on a co-primary basis. Thirteen years later, ITS saw its first pilot launch in Ann Arbor, Michigan.[24] Figure 5-1 shows the Department of Transportation's planned timeline for ITS. Over twenty years after Congressional authorization, DSRC remains in the R&D stage.

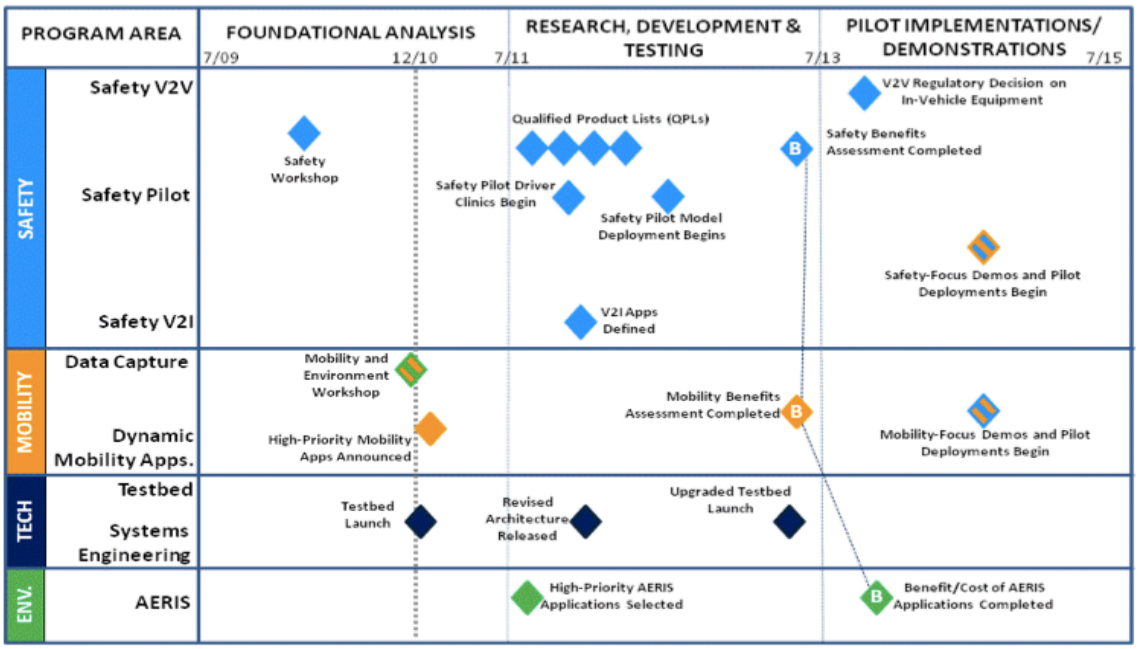

Figure 5-1: USDOT Work Plan for ITS/DSRC

The work on the physical layer standards used by ITS/DSRC technologies were started by ASTM International based on IEEE 802.11 standards, but was eventually moved to the IEEE 802.11 standards group itself. The standard was proposed as an extension to 802.11 and renamed 802.11p. In 2012, that standard was merged with

[23] ITS America has since become a 501(c)3 non-profit organization; as of March 17, 2003 the DOT no longer utilizes ITS America as its advisory committee on ITS matters.

[24] *See* Letter from ITS America to Julius Genachowski, then Chairman, FCC, *available at* http://www.itsa.wikispaces.net/file/view/ITS+America+Letter+re+5+9+GHz+Band+and+Connected+Vehicle+Program.pdf.

the over-all 802.11-2012 standard that includes the many variants of 802.11 networking. However, the "802.11p" name is still commonly used to refer to the specific part of 802.11 used for ITS applications.

ITS/DSRC is divided into channels that perform different functions, as seen in Figure 5-2 below. The spectrum is divided into seven 10 megahertz channels, each with a specific purpose. Channel 172 is used for vehicle-to-vehicle communication; channel 178 is a control channel used to coordinate the use of the other spectrum; channel 184 is for public safety vehicles and information about fixed traffic features such as intersections. These channels have specific applications tailored to mobile vehicle operations. The other channels (174 and 176, which can be combined for a 20 megahertz channel numbered 175, and 180 and 182, which can similarly be combined for channel 181) are "service channels" that are envisioned to provide a number of non-emergency services.

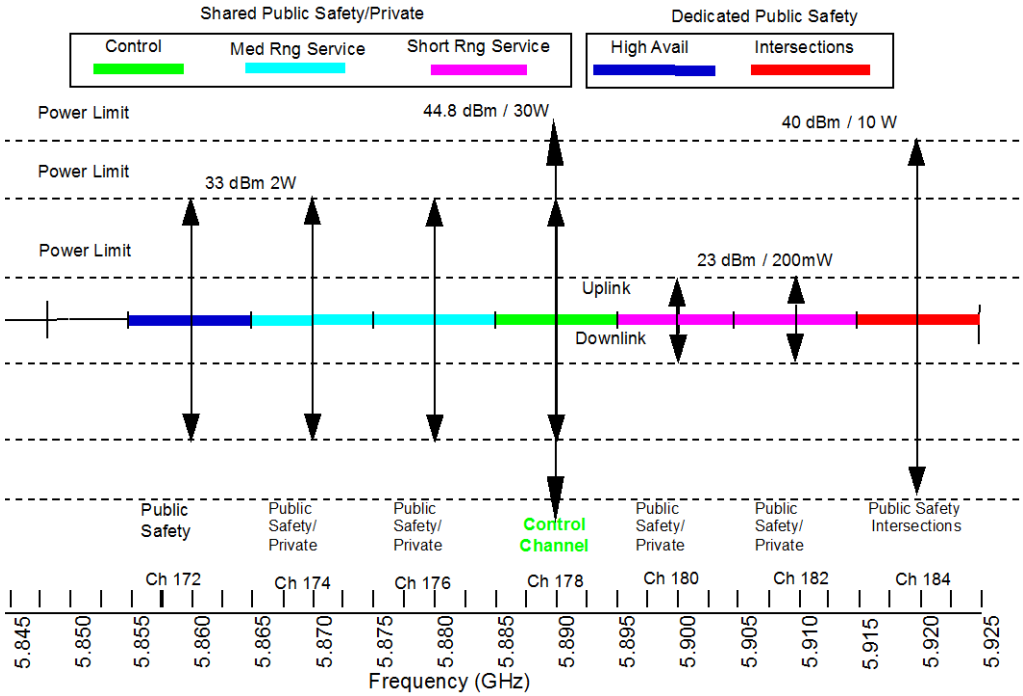

Figure 5-2: Spectrum Plan and Channel Assignment for DSRC

Vehicle-to-Vehicle (V2V) communication may be characterized as the highest-value application of DSRC, as it performs a safety function. Other technology solutions

seek similar outcomes through different means. Sensor-based crash avoidance services are in use today; however, these services are generally not linked to other vehicles, as DSRC would be. In some respects, currently available crash avoidance technologies may be more useful, as they can detect environmental factors (such as a car swerving off the road) that a narrower connected vehicle concept would not account for.

Approximately 10 times a second ITS/DSRC-equipped vehicles transmit "Basic Safety Messages" (BSM) on the control channel to inform others nearby of the vehicle's location, heading, trajectory, etc. On-board computers receive these Basic Safety Messages and translate them into a form drivers can understand. These messages are intended to provide information about nearby cars, rather than distant traffic conditions like traffic jams or general road conditions, although these applications are envisioned for the DSRC portfolio. Vehicles can also interact with infrastructure (V2I and I2V) to improve traffic flow and safety. For example, a stoplight may indicate that a light is about to change or the vehicle may inform the stoplight of a driver's intent by, for example, communicating turn signal information.

The other channels act as "service channels" that can be used for a variety of services, such as radio LAN (RLAN) networks, parking location, toll collection, or mobile payment methods. Some researchers envision using the DSRC spectrum to stream information between cars for coordinated, automated driving applications.

Other services are extensions to existing automated toll collection in the 900 MHz band. Those toll collection services were limited by a lack of standardization, which resulted in different transponders for different toll systems in the same band. The 915 MHz DSRC spectrum uses 12 megahertz of spectrum, but only achieves 0.5 Mbps throughput. By comparison, modern OFDM systems using the same spectrum should achieve 3-54 Mbps. The 915 MHz DSRC spectrum operates in an ISM band and must accept interference from other devices, but is widely used for commercial vehicle operations. Difficulty with unstandardized services in the 900 MHz band led

the Commission to take the unusual step and advocate for a specific technology standard in the 5.9 GHz band.

A "Proof of Concept" report on vehicular systems created for the Research and Innovative Technology Administration (RITA)[25] lists five tested DSRC applications: in-vehicle signage, traffic data collection to report road speeds and conditions, electronic payments, traveler information and navigation, location and speed of other vehicles, and traffic signal indication. The report indicated that although many of these applications were successful, some services suffered from the limited range offered in the 5.9 GHz band.[26] For example, Section 5.1.1 of the report found that because the 5.9 GHz spectrum is largely line-of-sight propagation, smaller vehicles had trouble meeting the target packet rate. Some systems, such as in-vehicle signage, could function with little bandwidth, but were ineffective without more information about the vehicle. The signage application requires information on the direction of travel as well as the actual compass heading. This implies that some services will require the vehicle to have a more sophisticated map of the area to make use of the broadcast signage. Services that used local communication, such as V2V Basic Safety Messages were delivered reliably at short ranges (50-75 m) but provided excessively detailed information.[27]

Since the initial vision for ITS, the market has furnished many of the services ITS had originally hoped to provide. Mapping and routing services, for example, are now provided through alternate technologies and spectrum – smartphones offer this functionality. At the time the DSRC spectrum was allocated, there were few widespread RLAN networks such as modern LTE-based carrier networks and few

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[25] VEHICLE INFRASTRUCTURE INTEGRATION CONSORTIUM, VEHICLE INFRASTRUCTURE INTEGRATION PROOF OF CONCEPT EXECUTIVE SUMMARY – VEHICLE, Submitted to the Research and Innovative Technology Administration, US DOT (May 19, 2009) *available at* http://ntl.bts.gov/lib/31000/31000/31079/14443_files/14443.pdf (RITA Report).

[26] For example, the route navigation and guidance service could only download partial directions from road-side equipment.

[27] The Basic Safety Message is transmitted approximately every 100 ms, or 10 times per second. If a car is travelling at 60 mph, the vehicle would be reporting its location and speed every 9 ft.

vehicles had GPS-based navigation system that included road maps of the entire continent. Today, these systems are common.

Several other applications envisioned for the DSRC spectrum have already been developed using GPS positioning and web technologies – for example, there are several city-specific and emerging national mobile applications to locate parking spots.[28] Services such as Google Maps and Tom-Tom provide real-time traffic monitoring.[29] The potential to use algorithms to extract such information from cellular networks has been well studied.[30] Other services go beyond simple traffic tracking and can, for example, determine how many people pass by a street corner at any given time, as well as demographic data of passers-by such as and the average annual income.[31]

While many of these services would require significant bandwidth if offered under DSRC, dramatic increases in storage and commercial computing power mean that the average smartphone can store many maps and routes. Those maps can be efficiently overlaid with up-to-date information about construction zones, traffic conditions, and consumer services through the web. These are all services originally conceived to use the DSRC spectrum, but are more effective and already accessible through the existing commercial ecosystem.

While many of the services that are supplanting DSRC are based on wide-area carrier networks using conventional smartphones, researchers have also experimented with using Wi-Fi networks for vehicular-to-infrastructure

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[28] *Smartphone Apps Put Parking Spots at Your Fingertips*, USA TODAY (Mar. 3, 2013), http://www.usatoday.com/story/news/nation/2013/03/03/mobile-parking-application/1946323/.

[29] *See*, *e.g.*, TomTom, *Live Traffic*, http://www.tomtom.com/livetraffic/.

[30] *See*, *e.g.*, University of California Berkeley, *Mobile Millennium*, http://traffic.berkeley.edu/ for information on partnership between UC Berkeley, Nokia Research, NAVTEQ and the California DOT to gather traffic information from the GPS in cell phones.

[31] *See* Mike Dano, *The sale of (anonymous) wireless users' location and behavior is already big business*, FIERCEWIRELESS (May 2013), http://www.fiercewireless.com/story/sale-anonymous-wireless-users-location-and-behavior-already-big-business/2013-05-23#ixzz2UnDEIECq

connectivity.[32] Other projects have studied how Wi-Fi could be extended to offer V2I and I2V networking.[33] The primary difficulty to date of using conventional Wi-Fi for vehicular applications has been the delay in the network authentication and security. The Wi-Fi industry is addressing these functions through HotSpot 2.0, as incorporated into the Passpoint specification of the Wi-Fi Alliance.

Similarly, Wi-Fi networks have seen wide-scale deployment since the DSRC spectrum proposal, and many businesses are experimenting with Wi-Fi-based services that appeal to smartphone users as well as vehicular users. Those services will be accessible to all users of Wi-Fi devices, not just vehicles outfitted with DSRC systems.

The DSRC standard must also compete with existing traffic safety technology, such as systems for priority control of traffic lights using infrared sensors and signaling, camera based automobile detection systems, and existing 900 MHz vehicular systems.

With rapid advances in computer vision and artificial intelligence, cars augmented with cameras can sense vehicles, lanes, and lights at intersections.[34] Many of these systems are outgrowths of a DARPA challenge for autonomous vehicles.[35] Vehicles competing in the DARPA challenges generally navigate using cameras, stored maps, and RADAR and LIDAR systems, and not DSRC.

The Google self-driving car was only recently made possible through rapid advancements in algorithms and increased availability of high-speed computers.

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[32] Robert Morris *et al.*, *CarNet: a scalable ad hoc wireless network system*, PROCEEDINGS OF THE 9TH WORKSHOP ON ACM SIGOPS EUROPEAN WORKSHOP, 61-65, *available at* http://doi.acm.org/10.1145/566726.566741

[33] The CarTel project at MIT has examined this in depth. *See* MIT CARTEL, http://cartel.csail.mit.edu/doku.php.

[34] *See* J. Levinson *et al.*, *Traffic light mapping, localization, and state detection for autonomous vehicles*, 2011 IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION (ICRA), 5784,5791 (May 2011).

[35] DARPA Urban Challenge; available at: http://archive.darpa.mil/grandchallenge/overview.asp

The Google car depends solely on on-board storage, processing, computer vision and a LIDAR ranging system for navigation.[36] Similarly, the new "Intelligent Drive" system developed by Mercedes-Benz foregoes ITS/DSRC, opting for cameras and radars instead.[37]

Researchers are seeking to reduce the cost of vehicle technologies by utilizing cheaper camera systems; wide adoption of these technologies seems more likely – and is further along – than DSRC.[38] In such vehicles, radio systems are only used for map updates and traffic conditions. Although these autonomous vehicles could benefit from real-time information about nearby vehicles, they will require significantly less bandwidth and infrastructure than DSRC engineers originally envisioned.

Technology advances in algorithms and computer processing will also facilitate more responsive emergency travel. Cities are installing synchronized stoplights, significantly improving traffic flow and assisting emergency response vehicles.

As these examples indicate, the success or failure of DSRC is an open question. In a recent study,[39] KPMG rated competing technologies using four metrics: cost, reliability, maturity and the dependence on regulatory mandates for sufficient adoption (See Figure 5-3). While DSRC-based technologies score high for reliability, they also score high for costs and regulatory dependence, which may significantly hinder the adoption rates needed for DSRC to be effective.

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[36] Eric Guizzo, *How Google's Self-Driving Car Works*, IEEE SPECTRUM, Oct. 2011, http://spectrum.ieee.org/automaton/robotics/artificial-intelligence/how-google-self-driving-car-works.

[37] Mercedes-Benz, *New Assistance Systems: The Helpers in the Background*, http://www.gavrila.net/Media_Coverage/Intelligent_Drive/2253283_10_New_assistance_systems_en.pdf.

[38] John Markoff, *At High Speed, On the Road to a Driverless Future*, N.Y. TIMES, May 27, 2013, *available at* http://www.nytimes.com/2013/05/28/science/on-the-road-in-mobileyes-self-driving-car.html?_r=0.

[39] KPMG, "Self-driving cars: The next revolution", November 2012.

Figure 5-3: KPMG Evaluation of Vehicle Communication & Sensor Technology

Drawbacks to DSRC are amplified by the technology's dependence on high adoption rates for success. DSRC components – particularly crash-avoidance applications – are only valuable to the extent there are others on the road with compatible DSRC systems. Cellular, GPS, sensor, and camera-based solutions are clearly winning the adoption race for many vehicular applications. These approaches also have inherent benefits over DSRC. For example, since these alternative technologies do not rely on specialized infrastructure, they could be available to pedestrians or those on public transportation, enhancing safety for all transportation users, rather than only those in cars. DSRC systems will be competing with many other technologies and may fail to reach the adoption rates required for viability.

Because of uncertain adoption, the availability of effective alternative technologies that provide duplicate DSRC applications, and in light of competing Wi-Fi use of the

spectrum, it is unclear that the current 75 megahertz allocation for DSRC remains warranted.

5.1.2 Contention Risk

Applications in the DSRC spectrum are broken into optional services and safety applications. Vehicle-to-vehicle (V2V) communication is likely to be most challenging for successful deployment. Because these novel, safety-related uses of DSRC rely on spectrum shared with other federal uses, there have been extensive studies of the potential for interference.

The 802.11p physical layer (PHY) is technically very similar to other 802.11 PHY layers. It uses an OFDM waveform with parameters chosen for mobile applications. But, unlike other standards, it also includes many extensions to handle real-time communication between moving vehicles.[40] Because of these novel applications, the media access control (MAC) layer is markedly different than other 802.11 layers. Stations communicate using a control channel (channel 178) and service channels. The network access time is divided into two distinct periods, with 50 ms out of every 100 ms devoted to control channel operation followed by 50 ms devoted to service channel operation. Each network participant needs an accurate clock so that all participants can listen to the control channel at the same time. As shown in Figure 5-2, only 10 megahertz is allotted for these control channel safety messages, and that spectrum is only used 50% of the time in the current standards.

Some ITS interests suggest the possibility of interference between 802.11ac and DSRC devices, and incorrectly assert that any interference is "harmful interference". For example, comments from the American Association of State Highway and

[40] For one of the best comprehensive overviews of DSRC applications, *see* John B. Kenney, *Dedicated Short-Range Communications (DSRC) Standards in the United States*, 99 PROCEEDINGS OF THE IEEE 7, 1162, 1182 (July 2011) *available at* http://secs.oakland.edu/~gpcorser/vanet-kenny-DSRC.pdf.

Transportation Officials (AASHTO) indicate that a single 802.11ac access point at 100ft elevation in Virginia Beach would cause interference along 10 miles of I-264.[41]

Such a claim ignores the important difference between the FCC's legal categories of "interference" and "harmful interference." Harmful interference is inference that "seriously degrades, obstructs, or repeatedly interrupts a radiocommunications service."[42] The AASHTO conducted its analysis by estimating the receiver sensitivity (typically -92 dBm), subtracting the signal-to-noise ratio for the desired modulation, and using that as the level for "interference."[43] The flaws in this methodology become clear when considering Wi-Fi systems interfering with one another. Under the AASHTO methodology a single Wi-Fi access point would undermine the operation of all other Wi-Fi devices within 10 miles. This is clearly *not* the experience of Wi-Fi users in the real world. Indeed, AASHTO's conservative standard for deeming interference "harmful" may completely preclude the spectrum sharing needed to maximize the value of this band.

In spectrum policy, we should be concerned with interference that harms a service to a meaningful degree. Generally speaking, if a signal is greater than the noise by a certain amount, it can be decoded. For the 6 Mbps rate commonly used for DSRC, the signal must be 6-7 dBm greater than the noise. That means if the noise is at -86 dBm, the DSRC signal needs to be received at -79 dBm in order to be decoded. Interference may limit the *range* of reliable reception, but it does not *eliminate* reception. Furthermore, the Wi-Fi standard (including the 802.11p variant used in DSRC) assumes that interference may occur and retransmits messages to improve the probability of correct reception.

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[41] Comments of American Association of State Highway & Transportation Officials in ET Docket 13-49, May 29, 2013 at 15.

[42] 47 C.F.R. § 2.1.

[43] As a side note, the analysis on page 7 of the AASHTO comments, *id.*, leads to a result where a higher, more error-prone modulation is less sensitive interference to a lower, more robust modulation.

Different vehicles within the ITS system may interfere with one another, as the DSRC MAC protocol of the Basic Safety Messages does not coordinate transmission from different vehicles. And yet the basic DSRC system can continue to function. The system assumes that the Basic Safety Messages aren't reliable on an individual-message basis. Instead, as explained further below, the Basic Safety Messages function using probabilistic reception over several attempts. Figure 4-4 shows the probability of successfully delivering basic safety messages using a single radio (lower line) and a radio dedicated to safety communications (middle line) as well two radios simultaneously (top line).[44]

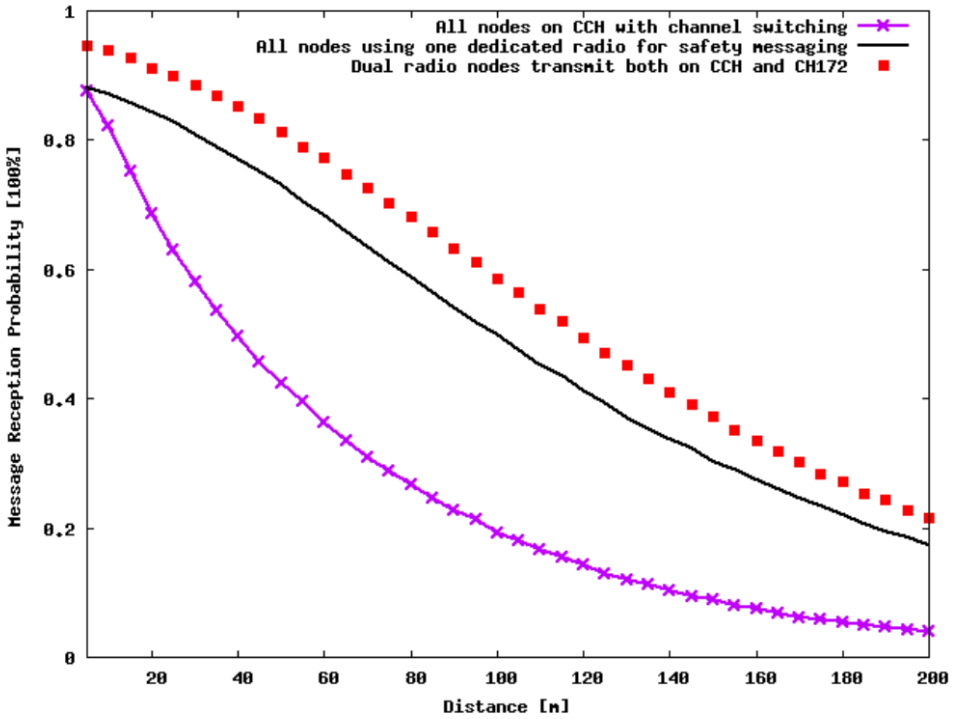

Figure 5-4: Analysis of Basic Safety Message Success

As originally specified, Basic Safety Messages were communicated on channel 178 during the control channel interval (half of the time). This analysis is from a 2010 Vehicular Technology Conference study that helped form consensus that V2V messages should always be transmitted on channel 172 during the full 100 ms

[44] Excerpted from Kezhu Hong, *et al.*, *Evaluation of Multi-Channel Schemes for Vehicular Safety Communications*, 2010 IEEE 71ST VEHICULAR TECHNOLOGY CONFERENCE, May 2010.

period, meaning that two radios would be needed.[45] Other studies have examined more efficient mechanisms to regulate the frequency of safety transmissions by using the car dynamics to predict future locations, rather than purely rely on messages.[46]

Under the current DSRC specification, which envisions transmitting V2V messages on channel 172, improvement from the dedicated radio results from using the full 100 ms period for safety messages, rather than splitting the time between control channel and service channel services. Figure 5-4 illustrates the limited range of such messages – only 20% of transmissions were received at 100m. Most DSRC research assumes that basic safety messages would have an effective range of 50-75 m, well short of the target range of 100 m. Despite the unreliable message delivery, the system still functions in tests. Because messages are sent every 100 ms, even a 20% success rate would result in a 67% success rate of a message being delivered within half a second, and a 90% success rate within a second.

The basic operation of the system is predicated on short-range, probabilistic message delivery. Although the interference from an 802.11ac access point will increase the noise floor, vehicles can still easily receive messages from nearby vehicles. Emergency response vehicles overcome some of these limitations by using highly directional antennas that extend the radio range in the direction of travel to signal stop light changes.

There are numerous sources of interference that affect the basic safety messages, including interference from adjacent vehicles operating on different channels within DSRC. Measurement studies in 2007 showed significant packet loss to the basic safety messages when nearby vehicles were transmitting on adjacent service

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[45] *Id*.

[46] For example, proposals have shown that it is possible to use vehicle motion to make more effective use of the control channel. *See* Shahram Rezaei *et al.*, *Tracking the position of neighboring vehicles using wireless communications*" 18 TRANSPORTATION RESEARCH PART C: EMERGING TECHNOLOGIES 3, at 335, June 2010.

channels.[47] This interference arises when an interfering radio is less than about 20% the distance of a transmitter-receiver pair. In other words, if the intended range of a BSM message is 100 m, then operating a "service channel" on a car closer than 20 m would cause significant packet loss in the BSM.

Again, the successful reception of a packet requires that the signal be larger than the noise. Most of the literature analyzing the 802.11p proposal assumes that the physical layer will use a QPSK-1/2 modulation for a 6 Mbps throughput. That modulation requires a signal-to-noise ratio of 6-7 dB. The path loss for 5.3 GHz spectrum in urban environments can be modeled by $PL=40.3+23.4 \log_{10}(d)$ for a distance "d" in meters (signals degrade with the square of the distance).[48] The 802.11p receiver specification requires a receiver sensitivity of -82 dBm to receive data at the 6 Mbps modulation; given that vehicles transmit packets at ~20 dBm, the 101 dB path loss is the basis for the nominal 400 m "packet range" specified in 802.11p.

Although BSM reception has been reported up to 2.5 km,[49] much of the experimental data shows that even the 400 m packet transmission ranges are aspirational, with practical reception ranges of 50-75 m being more realistic due to line-of-sight limitations associated with the 5.9 GHz band. This shortened range is also partially due to the "noise" of other vehicles transmitting in the distance; Wi-Fi access points would also appear as "noise" to the vehicles.

In other words, any interference risk to DSRC from Wi-Fi is on the margin, in combination with other environmental noise factors that exist today – suggesting

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47 *See* Vinuth Rai, *et al.*, CROSS CHANNEL INTERFERENCE TEST RESULTS: A REPORT FROM THE VSC-A PROJECT (July 2007) *available at* https://mentor.ieee.org/802.11/dcn/07/11-07-2133-00-000p-cross-%20channel-interference-test-results-a-report-%20from-the-vsc-a-project.ppt.

48 The study used data-fitting methods for line-of-sight and non-line-of-sight data. *See* Xiongwen Zhao, *et al.*, *Path-Loss Models for Urban Microcells at 5.3 GHz*, 5 IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, IEEE 152,154 (Dec. 2006).

49 S. Grafling, P. Mahonen, and J. Riihijarvi, *Performance evaluation of IEEE 1609 wave and IEEE 802.11p for vehicular communications*, PROCEEDINGS OF SECOND INTERNATIONAL CONFERENCE ON UBIQUITOUS AND FUTURE NETWORKS (ICUFN), 2010, at 344–348.

that coexistence can work with appropriate protocols. Since the path loss increases with the square of the distance, co-channel access points near or in the vehicle may have some impact on ITS systems, but Wi-Fi use further away would have considerably less impact. If ITS eventually comes to be widely deployed, a coexistence method will likely be needed, and the FCC should designate UNII-4 for Wi-Fi use so that Wi-Fi and ITS experts can devise such a system.

5.2 UNII-4 RADARs

Federal radar systems also populate the UNII-4 band and other segments of 5 GHz. Though the risk of interference from low-power Wi-Fi into high-power radar appears confined to limited and specific circumstances, the presence of radar allocations across UNII-4 and other parts of the 5 GHz band justify further exploration.

5.2.1 UNII-4 Radar System Architecture

Federal RADAR installations have affected the access rules for other services introduced to the 5.9 GHz band, and are explicitly addressed in the DSRC order. That order requires that, "operation of DSRC [roadside] stations within seventy-five kilometers of fifty-nine locations … must be coordinated through NTIA."[50] The area covered by those 75 km coordination zones are shown in Figure 5-6.

[50] FCC, Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz Band, *Report and Order*, WT Docket 01-90, Feb. 2004, ¶ 68.

Figure 5-6: Location of ITS/DSRC Protection Zones Due To Radar In UNII-4

The requirement for coordination of only one type of DSRC deployment – roadside stations – suggests a strong possibility for viable coexistence with Wi-Fi. In particular, the ubiquity required for DSRC effectiveness implies an expectation of widespread deployment on vehicles and infrastructure within the RADAR protection zones. Furthermore, radars operating in UNII-4 also extend across the UNII-3 band. The UNII-3 band currently allows for 1 Watt Wi-Fi deployments without additional interference mitigation techniques, indicating UNII-4 Wi-Fi-radar coexistence should be possible.

5.2.2 Contention Risk

Possible interference to RADAR has been analyzed by the NTIA using a computer model that simulates the interaction between RADAR receivers and a variable number of deployed Wi-Fi devices.[51] The results of that study were used to set the parameters used to prevent interference to RADAR.

[51] NTIA, U.S. DEP'T OF COMMERCE, NTIA REPORT 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 5GHZ RANGE (May 2009) *available at*

RADAR receivers are sensitive. Reported instances of interference have arisen from "line of sight" devices deployed by Wireless Internet Service Providers (WISPs) in UNII-2, where Terminal Doppler Weather Radar (TDWR) systems were impacted. WISP systems are more likely than Wi-Fi systems to cause interference to radars because they may be higher in elevation have an increased line of sight. The 75 km coordination zone specified in the DSRC rules would prevent interference from a 441 m (1440 ft) antenna located 75 km from the radar because 75 km is the "radio horizon" for such a tower.[52]

In an investigation into TDWR interference, the NTIA explained:

> "We have found that the interference at each location has generally been caused by a few fixed wireless transmitters used by wireless Internet service providers (WISPs) and operating outdoors in the vicinity of airports at high elevations that are line-of-sight to the TDWR installations (5 GHz outdoor network equipment). In most instances, the interference is caused by operations in the same frequency band as TDWRs, but there are some instances where the interference is caused by adjacent band emissions."[53]

Although there have been reported cases of interference with the TDWR, those cases occurred because wireless internet service providers explicitly ignored existing regulation, modified non-DFS capable radios to operate in a sub-band that requires DFS, and installed them on high towers with high-gain directional antennas in close proximity to TDWR installations. Also, some radios were properly DFS-certified but the DFS mechanism failed to operate as expected in the field.

The NTIA measured multiple FCC-labeled UNII devices to determine the separation distance *vs.* elevation for those devices.[54] Those separation distances closely

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http://www.ntia.doc.gov/report/2009/description-model-compute-aggregate-interference-radio-local-area-networks-employing-dyn (NTIA RADAR).

[52] An antenna 441m high would have a "radio horizon" of 75 km; this includes an expanded horizon due to increased propagation near the earth's surface.

[53] NTIA, INVESTIGATION OF INTERFERENCE INTO 5 GHZ WEATHER RADARS FROM UNLICENSED NATIONAL INFORMATION INFRASTRUCTURE DEVICES, PART I, TR-11-473.

[54] NTIA, INVESTIGATION OF INTERFERENCE INTO 5 GHZ WEATHER RADARS FROM UNLICENSED NATIONAL INFORMATION INFRASTRUCTURE DEVICES, Part III, TR-12-486.

matched the distance to the "radio horizon" – 25 km at 30 m antenna height, 75 km at 152 m, 95 km at 304 m – when the TDWR was assumed to have a 27m antenna height. Because of this interference, the FCC and a WISP industry group agreed that outdoor devices should operate with at least a 30 MHz separation if operating within 35 km of a TDWR.

As the NTIA analysis indicates, the interfering installations have been limited in number, were at high elevations or involved equipment modified to circumvent transmission controls, and were not related to consumer Wi-Fi equipment. Some of the interfering devices were shown to correctly detect the RADAR signal in the lab, but not when actually deployed. All of the interfering devices were used for long distance links by WISPs, and standard indoor deployments of Wi-Fi devices did not (and likely would not) cause interference.

This experience is instructive throughout the 5 GHz band where radar is present – close proximity, high-gain, high-elevation installations are most likely to cause radar interference. These operating parameters are also highly unusual for Wi-Fi, suggesting that interference risk is limited to a specific set of circumstances.

5.3 Fixed Satellite Service (FSS)

According to the FCC, the Fixed Satellite Service in UNII-4 is a lightly used service, limited to international, inter-continental delivery of content. Its nature as a lightly used international uplink service means it should not require Wi-Fi interference avoidance measures. That conclusion is confirmed by a brief technical review.

5.3.1 FSS System Architecture

FSS satellites are geostationary and orbit at equatorial latitudes approximately 35786.03 km[55] above the Earth's surface, as seen in Figure 5-8 below.

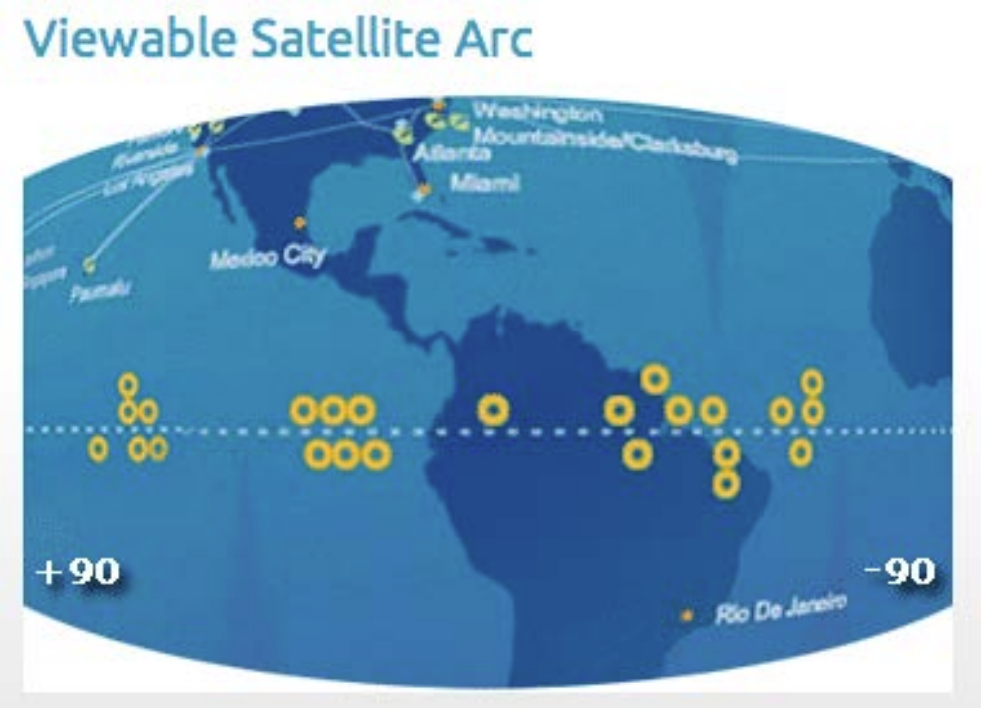

Figure 5-8: Location of Intelsat FSS Satellites (Castle Rock Teleport)[56]

The UNII-4 band overlaps with the extended C-band for uplink operations only; FSS downlinks are found in the 3.7 GHz – 4.2 GHz band. Most FSS satellites do not use the extended C-band, only using frequencies above 5.925 GHz for uplink communications, and are therefore not co-channel with UNII-4. However, some

[55] SES and Intelsat note in their joint comments to the FCC that FSS satellites orbit at approximately 22,236 miles above the Earth, or 35,786 kilometers. *See* Joint comments of SES and Intelsat in ET Docket 13-49, May 29, 2013. This distance likely refers to the closest point on the Earth's surface, not necessarily the United States.

[56] From Intelsat. See www.intelsat.com

satellites can receive signals in the extended C-band, as low as 5.85 GHz.[57] It is this smaller segment of FSS satellites that we analyze here.

5.3.2 Contention Risk

As noted above, a brief technical review confirms the FCC's conclusion that there is little risk to FSS systems from expansion of Wi-Fi access.

Consider a potential worst case interference scenario for FSS, in which a satellite uplink antenna covers a large portion of the contiguous United States. This scenario would be comparable to the circumstances analyzed in this report for the Globalstar's MSS system using the UNII-1 band. An important difference between MSS and FSS must be accounted for here, however: FSS satellites are geostationary and orbit at equatorial latitudes nearly 36,000 km above the Earth's surface.

This means that satellite orbital height and distance to Wi-Fi access points in the United States would result in a much larger Earth to space path loss than seen in the MSS context. Our critique of Globalstar's narrow 'single link' MSS interference analysis indicated that they significantly underestimate the number of Wi-Fi access points that would be required to meaningfully change the noise floor at the satellite beyond ITU Recommendations.[58] That recommendation defines the interference limit, or maximum noise floor, as a Power Flux Density (PFD) at the satellite antenna of -124 dB(W/(m2 • 1 MHz)).

We can apply this same standard to a FSS satellite system, with a simple adjustment for distance and relevant atmospheric losses, and find that the spreading loss to a GEO satellite that is approximately 35786.03 km[59] above the Earth's surface is

[57] For a review of FSS satellite technical specifications, see, for example Intelsat: http://exnetapps.intelsat.com/flash/coverage-maps/transperf.pdf

[58] *See* ITU Radiocommunication Sector, *Aggregate power flux density limits at the FSS satellite orbit for radio local area network transmitters operating in the 5150-5250 MHz band sharing frequencies with the FSS*, ITU-R S.1426.

[59] SES and Intelsat note in their joint comments to the FCC that FSS satellites orbit at approximately 22,236 miles above the Earth, or 35,786 kilometers. *See* Joint comments of SES and Intelsat in ET Docket

increased by a factor of 640 times, relative to MSS. This increase in Earth to space spreading loss implies that, for the same PFD limit, a GEO satellite can tolerate 640 times the amount of interference as compared to a MSS LEO satellite at 1414 km above the earth's surface.[60]

And, as noted previously, even if rules equivalent to UNII-3 are implemented in UNII-4, many Wi-Fi access points will actually operate indoors or at lower power levels, so Wi-Fi can be deployed even more broadly without risk to FSS, particularly since the universe of 5 GHz access points will be able to select channels across the full 5 GHz UNII band, not just UNII-4.

In addition, while we have more limited system information on FSS than we do on MSS, it is reasonable to assume that FSS satellites are 'bent pipe' in nature, as most satellite communications systems are. As explored in Section 4, this 'bent pipe' architecture, with no signal processing taking place on-board the satellite, means that a whole-system interference analysis framework is appropriate and preferable to the single-link approach described above. While we do not have sufficient technical information to conduct a fulsome end-to-end system analysis here, it is very likely that the limiting link in FSS systems is the downlink, as is in the MSS context, because of the scarcity of power on satellites relative to ground stations. There is therefore likely to be significantly more 'margin', or allowance for noise, in the FSS uplink than the downlink. As in the MSS context, this means that a whole-system interference analysis framework reveals that there is very little, if any, risk to satellite systems from Wi-Fi deployment.

It is also worth noting that extended C-band FSS systems can select from a broad range of channels that do not overlap with UNII-4. This one important foundation for the FCC's conclusion that this band is lightly used by FSS. The access regime for

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13-49, May 29, 2013. This distance likely refers to the closest point on the Earth's surface, not necessarily the United States.

[60] 1414 km is the approximate distance from Earth to an MSS satellite at zenith. See Figure 4-5 in this paper.

FSS in UNII-4 reflects this light use, as such deployments are authorized only on a case-by-case basis, with a compatibility analysis required to determine coexistence with terrestrial uses of the band.[61]

Given that over 500 megahertz of spectrum is available in the core C-band (3.7-4.2 GHz) for FSS operations, and without the restrictions that apply in UNII-4, it is logical that most FSS operations reside outside of UNII-4, and that the risk to FSS from expanding Wi-Fi use of the band is minimal, particularly given the technical observations noted here. More complete system information, including the precise extent of usage of the extended C-band, would enable a fulsome accounting of risks and provide a complete technical basis for sharing between FSS and Wi-Fi.

5.4 UNII-4 Conclusions

In expanding Wi-Fi access to UNII-4 to provide wide bandwidth harmonized with the adjacent UNII-3 band, coexistence with the incumbent DSRC, radar, and FSS services appears possible.

Because of uncertain adoption, the availability of alternative technologies that provide duplicate DSRC applications in a more effective and accessible manner, and competing Wi-Fi use of the spectrum, it is unclear if the ITS/DSRC project will be successful. However, since the IEEE manages both the 802.11p and 802.11ac standards, reason for optimism exists for the prospects of coexistence if ITS is deployed widely.

While publicly available technical information on Federal radars is scarce, the limited instances of interference to date suggests a very limited potential problem scope. Further information would yield greater insights on risks and potential coexistence strategies to manage any such 'corner cases'.

The Fixed Satellite Service (FSS) has little reason to be concerned with the expansion of Wi-Fi into UNII-4. Due to high orbital height of over 35,000 km, the risk

[61] *See* 47 C.F.R. §§ 2.106-2.108 (stating that "Case-by-case electromagnetic compatibility analysis is required with all users of the bands. It is anticipated that one earth station on each coast can be successfully coordinated.")

of breaching noise floor limits at the satellite is far less than in the Mobile Satellite (MSS) context. Further, the 'bent pipe' nature of FSS means that additional 'noise' from co-channel Wi-Fi use should have very little, if any, impact on a whole-system basis. For that reason, no special measures appear warranted to protect FSS.

6 Other Incumbents

This report has prioritized for analysis the incumbents that are most likely to pose technical challenges to expanding Wi-Fi use. We have reviewed these incumbent systems and determined interference risk, in order to inform the need for further research into coexistence mechanisms.

However, several systems are likely to have a low risk of Wi-Fi contention for various reasons, and have therefore not received the same level of scrutiny. We use this section to describe these systems and circumstances in somewhat more detail.

6.1 UNII-1 Aeronautical Mobile Telemetry (AMT)

The National Telecommunications and Information Administration (NTIA) noted in a February letter to the FCC that UNII-1 may become a new home for AMT systems currently operating in the 1755-1850 MHz band.[62] While it is the case that UNII-1 was mentioned as one possible home for AMT in a NTIA report,[63] it seems unlikely that this will occur.

Moving AMT systems from the 1755-1850 MHz band would only be done in conjunction with a broader move of most Federal systems out of that band. The mobile industry has expressed a primary interest in the 1755-1780 MHz portion of the band, so it is unclear why a large number of Federal systems would need to be vacated from the broader band. This is particularly the case since NTIA noted that

[62] Letter from Larry Strickling, Assitant Secretary for Communications and Information, U.S. Dept. of Commerce, to Julius Genachowski, then Chairman, FCC, *available at* http://apps.fcc.gov/ecfs/document/view?id=7022124722.

[63] NTIA, AN ASSESSMENT OF THE NEAR-TERM VIABILITY OF ACCOMMODATING WIRELESS BROADBAND SYSTEMS IN THE 1675-1710 MHZ, 1755-1780 MHZ, 3500-3650 MHZ, AND 4200-4220 MHZ, 4380-4400 MHZ BANDS, Oct. 2010, *available at* http://www.ntia.doc.gov/files/ntia/publications/fasttrackevaluation_11152010.pdf. The NTIA has also prepared a report specific to the 1755-1850 MHz band. *See* NTIA, AN ASSESSMENT OF THE VIABILITY OF ACCOMMODATING WIRELESS BROADBAND IN THE 1755-1850 MHZ BAND, Mar. 2012, *available at* http://www.ntia.doc.gov/files/ntia/publications/ntia_1755_1850_mhz_report_march2012.pdf.

the cost of doing so could be $18 billion, the effort could take 10 years, and would require use of 85 MHz of what is now commercial spectrum in exchange for the 95 MHz that would be released. Full federal relocation from 1755-1850 MHz therefore appears to lack merit, and it appears more likely that another solution will be found to accommodate commercial use of the bottom 25 MHz requested by the mobile industry.

However, even if AMT systems are to be relocated, the UNII-1 band is only one of seven options cited by NTIA in a 2010 report. Given the economic benefits of Wi-Fi, a complete analysis of alternative bands, which has not yet been performed, would likely reveal that the opportunity cost of moving AMT to UNII-1 is higher than other options. Indeed, the Government Accountability Office (GAO) has recognized that the estimated cost to relocate the federal incumbents operating in the 1755-1780 MHz band would increase the farther away on the spectrum the incumbents are required to move.[64]

Given the low likelihood of relocating AMT systems out of the 1755-1850 MHz band, and the availability of less costly alternative new bands for AMT if it is in fact relocated, no special measures should be taken to plan for AMT use of UNII-1. Consumers should not be deprived of the benefits of Wi-Fi in UNII-1 while the government takes years – and perhaps a decade or more – to determine the fate of AMT and other Federal systems in the 1755-1850 MHz band.

6.2 UNII-1 Microwave Landing Systems (MLS)

In setting the current conservative UNII-1 rules more than a decade ago, the FCC assumed that Microwave Landing Systems would occupy spectrum adjacent to that band. However, these systems never materialized and have now been overtaken by other technology, removing an important justification for restrictions in the current UNII-1 rules.

[64] U.S. Government Accountability Office, *Spectrum Management: Federal Relocation Costs and Auction Revenues*, Report to the Committee on Armed Services, U.S. Senate, at 21-22 (May 2013), *available at* http://www.gao.gov/assets/660/654794.pdf.

MLS was intended for aircraft navigation near airports. However, it is no longer in use. In 1994, the FAA suspended MLS in favor of other technologies, including GPS. MLS therefore poses no barrier to expanded Wi-Fi access in UNII-1.

6.3 Unmanned Aerial Systems Across UNII-2 and 3

Little information is available on Unmanned Aerial Systems that operate across the UNII-2 and UNII-3 bands. However, given their aerial nature and lack of interference evidence to date, it is unlikely that additional measures are required for coexistence with UAS.

6.4 Earth & Space Research in UNII-2a and 2c

Earth and Space Research systems are passive, receive-only systems used for scientific research. They have no ground-based receivers in the UNII bands; therefore, the risk of interference from Wi-Fi appears to be insignificant. In particular, if no changes are made to Wi-Fi transmit power levels in UNII-2a and UNII-2c, no additional accommodation should be required for these systems. If the Wi-Fi power level is increased, further analysis should explore what additional risks this may pose to these systems.

6.5 Meteorological Aids Service in UNII-2c

The Meteorological Aids Service is used for atmospheric measurements. Given its nature as a measurement-based service, and its current coexistence with Wi-Fi in UNII-2, it is unlikely that additional protections would be required.

7 Areas for Future Research on Coexistence

Given the diversity of incumbent allocations in the 5 GHz band, a range of coexistence needs and strategies are possible. Each potential approach to sharing the band has costs and benefits, and must be evaluated in the context of specific system circumstances.

As policymakers and industry experts explore spectrum sharing etiquette, it is important to base this effort on realistic and straightforward analysis of interference risk. Our goal in this paper has been to provide that technical foundation.

Sharing protocols should consider both the level of effectiveness in reducing any risks that may exist, as well as the effects on consumer benefits related to Wi-Fi use.[65] Both dimensions are important to inform spectrum access protocols, and the ultimate solution will ideally seek a balance between these two criteria.

Options that aim to maximize effectiveness and reduce interference risk to zero are likely to be highly intrusive and diminish or eliminate consumer Wi-Fi use. Similarly, strategies that seek to maximize consumer benefit may be ineffective in reducing any interference risk that may exist. Figure 7-1 shows a useful matrix for judging coexistence strategies, with effectiveness on the vertical axis, and consumer benefit on the horizontal axis.

[65] As noted previously, Richard Thanki estimates the total economic gain for households resulting from Wi-Fi at between $52 billion and $99 billion annually. THANKI, *supra* note 4.

Figure 7-1: Matrix for Evaluating Coexistence Strategies

This matrix may be used to overlay a 'menu' of coexistence strategies along the axes of benefit to consumers and effectiveness to select options that yield the appropriate balance.

As a general reference, several interference mitigation techniques are described below. These techniques may or may not be appropriate to the circumstances present at 5 GHz; future research should investigate their potential for reducing any interference risk to incumbent systems that may exist while maintaining a high level of consumer benefit from Wi-Fi.

- Geographic separation is one of the oldest regulatory mechanisms; by separating uses of the spectrum, the signals from stations using the same spectrum attenuate enough to eliminate meaningful interference.

- Geofencing solutions automate the management of geographic separation, controlling the deployment and use of transmitters in a region dynamically over time as the radio frequency environment evolves. More static approaches to geofencing are also possible to enable periodic updates to coexistence parameters, rather than coordination in real-time.

- Filtering is used both to limit the transmitted signal to specific spectrum and to reduce the effect of out-of-band emissions on reception. Increased filtering allows operation on adjacent channels, but does little to eliminate interference on the same channel.

- Dynamic frequency selection (DFS) refers to a "listen before talk" scheme that attempts to identify primary users of a frequency using characteristics of that primary user's signal. NTIA has published guidelines for DFS detection of RADAR in the 5 GHz band.[66]

- Beacons are explicit signals used to indicate the presence of primary spectrum users. There are two variants – one form is a constant signal that a station must hear in order to transmit.[67] The second variant is a periodic signal that indicates the presence of a station, possibly synchronized to a specific time or area. Beacons may use the same or a different channel than the protected signal and can also be used to mark receivers as well as transmitters.[68] Beacons can be added to signals that are difficult to detect, or

[66] NTIA RADAR *supra*, note 52

67 IEEE Std 802.22.1-2010, *Telecommunications and information exchange between systems Local and Metropolitan Area Networks, Part 22.1: Standard to Enhance Harmful Interference Protection for Low-Power Licensed Devices Operating in the TV Broadcast Bands* (Nov. 1, 2010) *available at* http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=5623446&contentType=Standards.

[68] T. X. Brown, *An Analysis of Unlicensed Device Operation in Licensed Broadcast Service Bands*, NEW FRONTIERS IN DYNAMIC SPECTRUM ACCESS NETWORKS & FIRST IEEE INTERNATIONAL SYMPOSIUM , 11-29, Nov. 2005.

an existing, easy-to-detect characteristic of a signal can function as a beacon. Beacons are generally combined with a mechanism that informs one contenting signal to 'back away', such as blanking.

- Blanking is a technique for sharing spectrum in the time dimension, and involves disabling a signal for a short duration to avoid contention with another radio system.

Coexistence analyses should be circumstance-specific, tailored to system needs and risks. Our goal in exploring the implicaitons of expanded Wi-Fi access in 5 GHz is to provide a solid technical foundation for this further analysis. While we do not endeavor definitive or detailed proposals for coexistence mechanisms here, it is worth noting what our technical analyses may suggest as potentially promising paths. We recognize that these suggestions require further research before they can be fully judged.

7.1 MSS Coexistence

Policymakers should consider the real-world impact of interference mitigation measures designed to protect MSS at the cost of Wi-Fi access. In terms of spectral efficiency, Wi-Fi is a far more efficient use of the UNII-1 spectrum than MSS.

Globalstar served approximately 562,000 total subscribers in 2012, of which less than 100,000 subscribed to their duplex service that uses the 5.2 GHz band for uplink.[69] If one half of these users are in the US, then there are approximately 50,000 US Globalstar users of the 5 GHz band. This number represents less than 0.02% of the entire US population – a small number that is monopolizing approximately 159 megahertz of valuable 5 GHz spectrum, and using it for

[69] Globalstar Annual Report, FORM 10-K, for the fiscal year ended December 31, 2012. Globlastar reported 88,189 duplex subscribers at the end of 2012, down almost 6,000 from the prior year. Other Globalstar services include the simplex and SPOT service, which use different bands (SPOT uses 1.7 GHz for uplink and 7 GHz for downlink, for example).

narrowband services at a time when the FCC is working to increase wireless broadband availability. Overly protective rules have a very real cost. Globalstar can therefore be seen as seeking to protect a small number of users at the expense of widespread broadband access.

The inefficiency of such an approach can be quantified further in spectral efficiency terms. If all 50,000 US users are able to receive the maximum Globalstar data rate of 9.6 kbps, this equates to a total data throughput of 480 Mbps. That is to say, the MSS industry is serving, at most, approximately 480 Mbps to US users while using 159 megahertz of spectrum.[70] A data delivery rate of 480 Mbps in 159 megahertz of spectrum would be a spectral efficiency of about 3 bits per Hertz.

In comparison, unlicensed use of this spectrum would make use of four 20 MHz 802.11ac channels in the UNII-1 band. Not considering spatial multiplexing, each channel could conservatively yield 80 Mbps, or 320 Mbps in the bandwidth of UNII-1, 100 megahertz. If there were 70,000 UNII-1 access points in the US, with a 10% duty cycle evenly distributed among the four channels, this would yield 560 billion bps in the 100 megahertz of UNII-1 spectrum. This is roughly, 5600 bits per hertz – nearly 1,900 times more efficient than MSS, and a far better use of spectrum resources. And, since the number of UNII-1 access points could be conceivably higher than 70,000, this MSS inefficiency is perhaps much greater than quantified here.

Current restrictions on Wi-Fi use of UNII-1 are designed to protect MSS systems that also use the band. However, these protections were designed prior to the deployment of MSS, so the time is right to reassess.

We have demonstrated that in their 'single link' analytic approach, measuring the noise floor at the satellite from Wi-Fi, Globalstar overstates the risk of interference greatly. We have also outlined how a superior analytic approach, analyzing risks on a whole system basis, would take more specific account of Globalstar's system needs,

[70] We have assumed best case here in that the data stream is continuous and full time.

and indicates that increasing Wi-Fi use of UNII-1 should have no impact to Globalstar's system.

These findings suggest that minimal, if any, special interference protections are warranted. To the extent that further study of such protections are desired, the focus should be on a dynamic approach that takes specific account of incumbent system needs and actual Wi-Fi deployment. Static approaches based on overly conservative technical analysis are likely to unnecessarily limit the benefits that consumers might enjoy from expanded Wi-Fi use.

7.2 ITS / DSRC Coexistence

The uncertainties surrounding the efficacy, proper scope, and ultimate success of the ITS / DSRC project should also give policymakers pause in designing interference protections that may diminish Wi-Fi use. However, should this technology realize wide adoption, the IEEE 802.11 process should provide an appropriate forum for industry experts to determine a sharing etiquette.

We have observed that ITS / DSRC operates on a probabilistic basis, with messages sent many times to enhance success rates. The fact that ITS / DSRC is a time-based system suggests that a time-based sharing mechanism may be a productive path for further study. Wi-Fi devices should be able to easily detect signals from DSRC enabled vehicles. Since the 802.11p standard is based on the same technology as other 802.11 network physical layers, 802.11 access points might be modified, if needed, to scan the 802.11p control channels to determine if that spectrum is being used for DSRC applications.[71]

It may also be possible for vehicles to emphasize their presence and strengthen the beacon used to keep out other uses of the DSRC spectrum. Wi-Fi radios already rely on coexistence mechanisms through "carrier sense." Wi-Fi radios first listen to

[71] The 802.11p PHY standard was advocated in large part because the large Wi-Fi market, coupled with the simple extensions needed, would allow inexpensive and widespread use of 802.11p devices. The 802.11p portion uses different OFDM carrier spacing than the wider channels used for 802.11ac, and detection of 802.11p would require additional effort. However, we assume that most Wi-Fi chipsets would support the 802.11p PHY as well as 802.11ac for economies of scale.

determine if there is too much noise (indicating a likely on-going transmission); the radio only transmits if the noise level is below a programmed threshold.[72] Even though DSRC messages are short (typically ~300 bytes, which take ~0.5 ms to transmit), 802.11ac messages are even shorter because they are modulated across 160 megahertz. Because the DSRC radio will be placing all of its 20 dBm of power in the 10 megahertz control channel, the Wi-Fi carrier sense mechanism could likely detect a DSRC packet, causing the 802.11ac device to delay transmission.

These initial concepts are not inclusive of all coexistence paths that may be considered to enable coexistence between ITS / DSRC and Wi-Fi. For example, we have observed that the core basic safety messages of DSRC are likely to require only 10 MHz of spectrum, which in combination with broad commercial duplication of DSRC functions, suggests that a reassessment of the DSRC band plan could be studied. That reassessment could in turn enable greater Wi-Fi use.

Given the immediate economic and consumer benefits of expanding Wi-Fi in the 5 GHz band, we believe that collaborative field testing should proceed expeditiously, involving both incumbents and the WiFi industry, around promising spectrum sharing solutions that will lead to the adoption of rules that will unleash this spectrum for unlicensed use while ensuring that ITS will be able to co-exist in this band.

7.3 Radar Coexistence

As we have explored, based on available information it appears that the interference risk to radar is limited to a specific set of operating parameters that are unusual for Wi-Fi. For that reason, coexistence strategies should address risks directly and narrowly, minimizing the cost of protection measures.

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72 Our measurements in 2005 showed that commercial Wi-Fi chipsets have very accurate noise floor measurement mechanisms; *see* Dirk Grunwald, *et al.*, *SoftMAC - Flexible Wireless Research Platform*, Fifth Workshop on Hot Topics in Networks, 2005.

One historic means of protecting radars has been to develop exclusion zones around a wide geographic area, precluding commercial use near a fixed installation. However, since these zones fully preclude the realization of any commercial benefits within the zones, and are ineffective in protecting mobile installations, dynamic frequency selection (DFS) methods have also been used to require that unlicensed radios read the RF environment in search of radar signals.

The DFS requirement as implemented today deserves additional scrutiny. Although DFS is designed to prevent interference with RADAR, it also inadvertently prevents the spectrum from being used even when there is no RADAR present. Reports from WISPs indicate that the DFS mechanism is overly conservative, and that the DFS mechanism can be triggered by "false positive" signals arising from sunspots and adjacent channel communication.[73]

Following the DFS rules, each false positive report causes the channel to be vacated for 30 minutes. Because a Wi-Fi access point must continuously monitor the spectrum during idle periods, a very low false positive rate may lead to the channel being vacated for very long periods of time – even very rare events happen when measurements are conducted frequently. Figure 7-2 shows the results of conducting a Monte Carlo simulation following the parameters used in ITU-R M.1652 to determine the probability of correctly identifying the RADAR signal.

[73] Brett Glass, *Shared Spectrum, Sunspots, and the Birthday Paradox: Lessons Learned from Sharing of the 5.4-5.7 GHz Frequency Band*, TPRC 2013, *available at* http://ssrn.com/abstract=2032299.

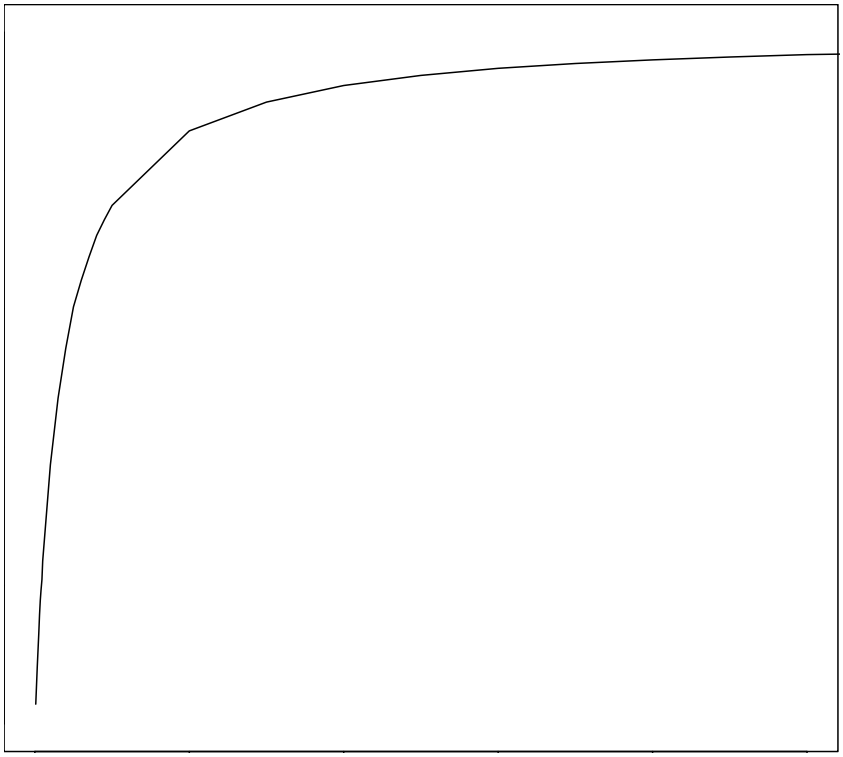

Figure 7-2: Percentage Of Time Channel is Vacated Due to DFS False Positives

In this model, a single radio transmitter-receiver pair transmits messages and monitors the channel during idle periods; during those idle periods, the DFS mechanism may incorrectly indicate the presence of a TDWR with a specified probability, causing the channel to be vacated for 30 minutes. In Figure 7-2, the horizontal axis is the probability of a false positive expressed as a percentage, and vertical axis is the percentage of time the channel is vacated due to false positives.

This simple model comports with WISP experiences – the channel becomes essentially unusable for ISP operations, with a 1-in-5000 false positive rate leading to the channel being vacated roughly 80% of the time. While specific false positive rates have not been documented in the field, and DFS equipment may improve over time, this simulation highlights the problem of non-cooperative techniques – even the rare "black swan" of a false positive can cause the spectrum to lie fallow for large periods of time.

The use of DFS as it is known today may therefore not be the optimal coexistence strategy. In addition to the potential for false positive detections by Wi-Fi access points, the DFS mechanism complicates radar operation when changing waveforms (for example, through a system upgrade), because the new waveform may not comport with DFS detection mechanisms.

Cooperative sensing, wherein radar explicitly announces its presence to the access point, rather than requiring the access point to scan the environment for a radar footprint, may be more efficient. However, the costs and efficacy of this approach will require more in-depth analysis. Other options are also possible that enable a more dynamic approach to sharing with radars, perhaps, for example, to take advantage of radar duty cycles.

Looking beyond "one size fits all" rules will enable greater spectrum utilization, and openness to new technology advances can enable dynamic management of access terms in a manner that works better for all stakeholders.

7.4 FSS Coexistence

Based on available information, our analysis indicates that there is little risk to FSS from expansion of Wi-Fi access into UNII-4. Therefore, there is no compelling justification for adoption of restrictions on Wi-Fi to protect FSS. More complete system information, including the precise extent of usage of the extended C-band, would enable a fulsome accounting of risks and provide a complete technical basis for sharing between FSS and Wi-Fi.

8 Conclusion

This report has taken a rigorous approach to analyzing coexistence between expanded Wi-Fi access and other services that share the 5 GHz band. While the coexistence issues posed by incumbent services are each different, our analysis has demonstrated that there are many paths toward expanding Wi-Fi access to the band, as the FCC has proposed. The ultimate approaches chosen by regulators to facilitate Wi-Fi use should ensure that the consumer benefits of Wi-Fi are advanced, allowing the wireless broadband ecosystem to continue to flourish.

The 5 GHz band represents a unique opportunity to ensure adequate capacity for continued growth of Wi-Fi. 802.11ac, the latest mass-market Wi-Fi technology that offers gigabit speeds using 5 GHz spectrum, but only if the terms of access are made more favorable by regulators. The full potential of 802.11ac is only realized with wider channels, and more spectrum.

Wi-Fi is a key component of the wireless broadband ecosystem. As such, it is an important part of the nation's economic infrastructure. As Wi-Fi use has grown and become ever more important to consumers, it risks exhausting the available wireless spectrum capacity.

The need for additional spectrum for wireless broadband is not a new or controversial idea. The time is right for continued progress toward this goal.