

PHOENIX CENTER POLICY BULLETIN NO. 40

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SKIN IN THE GAME:

INTERFERENCE, SUNK INVESTMENT, AND THE REPURPOSING OF RADIO SPECTRUM

Abstract: In this BULLETIN, we attempt to shed some light on the optimal design of Commission rules and practices for addressing interference disputes. Since spectrum licenses produce no benefits without large and mostly sunk investments in communications networks, our focus is on investment incentives. We argue that the Federal Communications Commission's optimal interference policy would necessarily deal with different license holders differently when their sunk network investments vary. We focus on sunk investments because if interference-causing repurposings are permitted and the significant sunk assets to provide services using spectrum are given short shrift, then the rational response of private parties is to curb investment. A reduction in investment will reduce the value of wireless services and, in turn, the value of the spectrum. Accordingly, our model of interference dictates that license holders who have made little or no sunk investment in capital to generate benefits from their license would receive little relief under an optimal rule. On the other hand, those licensees with substantial sunk network investments would receive far more expansive treatment by the regulator. Put bluntly, regulatory policy towards interference concerns should favor those licensees with more "skin in the game," with attention focused on actual capital investments in networks and not spectrum licenses alone. To provide context, we use the continuing saga of LightSquared Networks-a spectrum speculator now branded as Ligado – as a case study, though the analysis is in no way limited to the specifics of this ongoing proceeding.

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I. Introduction

Radio spectrum is a scarce and finite resource, essentially all of which has been allocated to particular uses and licensed to commercial, non-commercial, or government users.¹ Many of these allocations and assignments were made decades ago and no longer reflect the economic realities of wireless communications. Federal agencies responsible for spectrum management — the National Telecommunication and Information Administration ("NTIA") and the Federal Communications Commission ("FCC")—are searching for unused or underutilized spectrum that can be reallocated or reassigned to more valuable uses.² The private sector is doing its part through secondary-market transactions.³ But as spectrum gets moved about to suit modern demands, interference problems within and across spectrum bands are certain to arise. Federal Communications Commission policies on interference could have significant effects on the wireless marketplace: poor interference management could sabotage existing services, affect the value of spectrum licenses and, most importantly, attenuate investment incentives for wireless networks.

¹ For a table of current frequency allocations, *see* https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation.

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FCC, CONNECTING AMERICA: THE NATIONAL BROADBAND PLAN 84 (2010) (hereinafter "National Broadband Plan") (available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-296935A1.pdf); NAT'L TELECOMM. & INFO. ADMIN., PLAN AND TIMETABLE TO MAKE AVAILABLE 500 MEGAHERTZ OF SPECTRUM FOR WIRELESS BROADBAND (Oct. 2010) (available at http://www.ntia.doc.gov/category/spectrum-management. Some progress has been made. Assuming the incentive auction is a moderate success, it will repurpose nearly 100MHz of low-band spectrum to mobile broadband use (https://apps.fcc.gov/edocs_public/attachmatch/DA-15-606A1.pdf). The H-Block Auction (10 MHz) in 2014 and the AWS-3 auction in 2015 (65MHz) repurposed 75 MHz of mid-band spectrum for mobile wireless use (http://wireless.fcc.gov/auctions/default.htm?job=auctions_all). In 2014, the FCC freed up 100 MHz in the lower 5 GHz band for Wi-Fi operations (https://apps.fcc.gov/edocs_public/attachmatch/DOC-326341A1.pdf). However, the challenge continues. See T.R. Beard, G.S. Ford, L.J. Spiwak and M. Stern, Market Mechanisms and the Efficient Use and Management of Scarce Spectrum Resources, 66 FEDERAL COMMUNICATIONS LAW JOURNAL 263 (2014) (available at: http://www.fclj.org/wp-content/uploads/2014/06/66.2.2_Spiwak-Final.pdf).

T.R. Beard, G.S. Ford, L.J. Spiwak and M. Stern, *Taxation by Condition: Spectrum Repurposing at the FCC and the Prolonging of Spectrum Exhaust*, 8 HASTINGS SCIENCE AND TECHNOLOGY LAW JOURNAL 183, 185-86 (2016) (available at: http://www.phoenix-center.org/papers/HastingsSTLJ-TaxationbyCondition.pdf) ("we have recently seen activity involving the conversion of spectrum currently used for Mobile Satellite Service (MSS) to terrestrial use, the acquisition and conversion of WCS spectrum to commercial use, and the transfer of idle spectrum licensed to the cable industry to a mobile broadband provider"); M. Alleven, *NTIA: Significant Progress Made in Reaching 500 MHz Goal by 2020*, FIERCEWIRELESS (June 22, 2016) (available at: http://www.fiercewireless.com/tech/ntia-significant-progress-made-reaching-500-mhz-goal-by-2020); *Sixth Interim Progress Report on the Ten-Year Plan and Timetable*, NTIA (June 17, 2016) (available at: https://www.ntia.doc.gov/files/ntia/publications/ntia 6th interim progress report on ten-year timetable june 2016.pdf).

In this BULLETIN, we attempt to shed some light on the optimal design of Commission rules and practices for addressing interference disputes. Since spectrum licenses produce no benefits without large and mostly sunk investments in communications networks, our focus is on investment incentives. We argue that the Agency's optimal interference policy would necessarily deal with different license holders differently when their sunk network investments vary. As we explain in detail below, it is important to focus on sunk investments because if interference-causing repurposings are permitted and the significant sunk assets to provide services using spectrum are given short shrift, then the rational response of private parties is to curb investment. A reduction in investment will reduce the value of wireless services and, in turn, the value of the spectrum. Furthermore, consumers are frequently required to make sunk investments in wireless technologies to use the services of their providers. If consumers sense that these personal investments may be stranded by federal policy, then consumers will reduce their personal investments and the value of the wireless sector will decline. So, while federal agencies must repurpose spectrum to create value, they also must avoid destroying value through the unartful management of interference. Accordingly, our model of interference dictates that license holders who have made little or no sunk investment in capital to generate benefits from their license would receive little relief under an optimal rule. On the other hand, those licensees with substantial sunk network investments would receive far more expansive treatment by the regulator. Put bluntly, regulatory policy towards interference concerns should favor those licensees with more "skin in the game," with attention focused on actual capital investments in networks and not, as we discuss, spectrum licenses alone.

To provide context, our exposition is framed within, but in no way limited to, the continued saga of LightSquared Networks, a spectrum speculator now branded as Ligado after emerging from bankruptcy. Ligado has labored for years to repurpose 40 MHz of satellite spectrum for terrestrial mobile broadband use, thereby increasing the spectrum's market value. However, Ligado's proposal has been held up by serious and ongoing interference concerns. Significant interference concerns have been raised, for instance, by the Federal Aviation Administration ("FAA"), the NTIA, the Global Positioning Satellite ("GPS") sector, the National Oceanic and Atmospheric Administration ("NOAA"), and Iridium Communications (among others), many of which have made and many of which rely upon significant sunk investments in satellites, base stations, and other communications equipment.

II. Repurposing, Interference and Investment

Many, if not most, spectrum allocation decisions were made decades ago and reflect the technology and business environment of the past. Now, faced with spectrum shortages in mobile wireless communications, the NTIA and FCC are frantically looking for spectrum to repurpose

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for wireless and mobile wireless broadband.⁴ The current shortfall in spectrum was estimated by the FCC at a whopping 500 MHz, though others claimed the deficit was even greater.⁵ Since most spectrum bands are already allocated to uses and assigned to users, the FCC and the NTIA are charged with the difficult task of finding unused or underutilized spectrum that could be taken from existing licensees and repurposed to uses with greater demand. Private actors are doing their part, moving spectrum among established players in secondary market transactions and assuming the risk of cobbling together portfolios of spectrum assets, some of which is restricted in some way (like Ligado's spectrum), to sell at some future date.⁶

Wrestling spectrum away from current licenses and secondary market transactions can be difficult work, but complicating matters further for these federal agencies is the fact that spectrum is not always fungible. The usefulness of certain radio frequencies can be materially degraded by the use of nearby frequencies for the same or other purposes due to out-of-band emissions ("OOBE") and in-band emissions ("IBE").⁷ The quagmire faced by federal spectrum authorities is laid out plainly in a white paper by the FCC Technical Advisory Council:

In order to meet the growing demand for wireless service, the number of wireless systems that operate in close proximity in frequency, space and time needs to increase. Closer packing brings many benefits, including increased access, new

⁴ See, e.g., Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband, NTIA (October 2010) (available at: https://www.ntia.doc.gov/files/ntia/publications/tenyearplan_11152010.pdf); Presidential Memorandum: Unleashing the Wireless Broadband Revolution, Memorandum for the Heads of Executive Departments and Agencies, The White House (June 28, 2010) (available at: https://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution); Memorandum of Understanding between the Federal Communications Commission and the National Telecommunications and Information Administration (January 1, 2003) (available at: https://www.ntia.doc.gov/files/ntia/publications/fccntiamou_01312003.pdf).

⁵ National Broadband Plan, supra n. 2; R. Clarke, Expanding Mobile Wireless Capacity: The Challenges Presented by Technology and Economics, 38 TELECOMMUNICATIONS POLICY 396-708 (2014) (available at: http://www.sciencedirect.com/science/article/pii/S0308596113001900).

⁶ Indeed, regardless of the price paid in the secondary market, the FCC's jurisdiction over spectrum allocation and use is absolute. As such, there is always a potential risk that the Commission may not find a particular application to repurpose spectrum to be in the public interest. *See, e.g.,* 47 U.S.C. § 316.

⁷ See, e.g., T.W. Hazlett and E.T. Leo, *The Case for Liberal Spectrum Licenses: A Technical and Economic Perspective*, 26 BERKELEY TECHNOLOGY LAW JOURNAL 1037, 1039 (2011) ("... interference between radio signals is real and [] conflicts between rival users are expensive. To productively use spectrum inputs for one set of applications or technologies constrains what such inputs can supply for alternatives.").

services, and device innovation. However, tighter proximity also increases the risk of service disruptions due to inter-system interference.⁸

Such interference, which is a fundamental issue in wireless network engineering, is typically mitigated by technical means such as power limitations and boundaries between interfering frequencies (i.e., guard bands). Interference may also be addressed by assigning users and uses varying degrees of priority (i.e., primary, secondary, and so forth), thereby requiring some users to tolerate more interference than other users. When the parameters of interference are known in advance of network construction, service providers may be able to design their networks and manage their spectrum to render a high quality service. Nonetheless, repurposing spectrum in one band may be severe enough to destroy business plans or require expensive and extensive upgrades or modification to equipment in another. While federal agencies must shift spectrum to higher-valued uses, this reshuffling of the spectrum deck is a complex task.

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⁸ Interference Limits Policy the Use of Harm Claim Thresholds to Improve the Interference Tolerance of Wireless Systems, White Paper by the Receivers and Spectrum Working Group, FCC Technological Advisory Council (February 6, 2013) (available at: https://transition.fcc.gov/bureaus/oet/tac/tacdocs/WhitePaperTACInterferenceLimitsv1.0.pdf).

⁹ See, e.g., S. D'Oro, P. Mertikopoulos, A. L. Moustakas, S. Palazzo, Interference-Based Pricing for Opportunistic Multi-Carrier Cognitive Radio Systems 14 IEEE Transactions on Wireless Communications (Dec. 2015) (available at: https://pdfs.semanticscholar.org/4315/9e2c3278ec3c001e85648d6eab2300d826b9.pdf); C. Doyle, The Pricing of Radio Spectrum: Using Incentives Mechanisms to Achieve Efficiency, Center for Management Under Regulation, Warwick Business School (2007) (available at: http://www.itu.int/osg/spu/stn/spectrum/workshop-proceedings/Background_Papers_Final/Spectrum%20Libe-ralisation%20and%20Interference%20Management.pdf; http://dl.acm.org/citation.cfm?id=2333141.2333473).

See, e.g., Redesignation of the 17.7-19.7 GHz Frequency Band, Blanket Licensing of Satellite Earth Stations in the 17.7-20.2 GHz and 27.5-30.0 GHz Frequency Bands, and the Allocation of Additional Spectrum in the 17.3-17.8 GHz and 24.75-25.25 GHz Frequency Bands for Broadcast Satellite Service Use, 13 FCC Rcd. 19923 at n.4 (1998) ("a secondary service is allowed to use the band as long as its operations do not cause interference to any primary designated operations. If a secondary service operation causes interference to a primary service, the secondary service provider must cease operation [and] a service designated as primary is the only service given priority status to operate in a frequency band. A service designated as co-primary must share operations with other services designated as co-primary in the frequency band on a co-equal basis"). By Commission rules, secondary users must also accept interference from primary users.

Some ideas on addressing interference in the modern world are enumerated in *Introduction to Interference Resolution, Enforcement, and Radio Noise,* White Paper by the Spectrum/Receiver Performance Working Group, Federal Communications Commission, Technical Advisory Council (June 10, 2014) (available at: https://transition.fcc.gov/bureaus/oet/tac/tacdocs/meeting61014/InterferenceResolution-Enforcement-Radio-Noise-White-Paper.pdf).

The Commission's interference rules and practices are complex and varied, and covering the full breadth and depth of such rules and policies is beyond the scope of this BULLETIN. Instead, we focus our attention by considering the well-known case of Ligado Networks—known more widely by its former corporate name LightSquared—and the interference rules governing its spectrum. Since 2010, Ligado Networks has attempted the repurposing of 40 MHz of spectrum from satellite services to mobile broadband use. Technically speaking, this repurposing involves a modification to Ligado's licenses to expand the bounds of its Ancillary Terrestrial Component ("ATC"), which normally allows a service provider to use terrestrial towers in support of its mobile satellite service ("MSS"). Yet, Ligado does not own or operate a MSS network of any significance. Instead, with the 40 MHz of spectrum in question, Ligado's plan is to construct and operate a terrestrial network as a wholesale platform, offering access to spectrum and mobile service to retail service providers. The business case for such a network is highly speculative, but it is reasonable to expect the modified licenses to sell at a profit in the secondary market. Ligado's plans have evolved over the years in response to interference

LightSquared Networks came into existence in 2010 with the merger of SkyTerra and Harbinger Capital. *In the Matter of SkyTerra Communications, Inc. and Harbinger Capital Partners Funds, Applications for Consent to Transfer of Control,* DA 10-535, MEMORANDUM OPINION AND ORDER AND DECLARATORY RULING, 25 FCC Rcd. 3059 (rel. March 26, 2010) (hereinafter the "*Harbinger Order*").

¹³ LightSquared Subsidiary LLC Request for Modification of its Authority for an Ancillary Terrestrial Component, SAT-MOD-20101118-00239 (filed Nov. 18, 2010).

Repurposing MSS spectrum has precedent. In the recent past, the Commission approved ATC modifications for MSS spectrum for both Dish Networks and Globalstar. See, e.g., In re Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands; Fixed and Mobile Services in the Mobile Satellite Service Bands at 1525-1559 MHz and 1626.5-1660.5 MHz, 1610-1626.5 MHz and 2483.5-2500 MHz, and 2000-2020 MHz and 2180-2200 MHz; Service Rules for Advanced Wireless Services in the 1915-1920 MHz, 1995-2000 MHz, 2020-2025 MHz and 2175-2180 MHz Bands, FCC 12-151, REPORT AND ORDER AND ORDER OF PROPOSED MODIFICATION, 27 FCC Rcd. 16102 (rel. December 17, 2012); In re Terrestrial Use of the 2473-2495 MHz Band for Low-Power Mobile Broadband Networks; Amendments to Rules for the Ancillary Terrestrial Component of Mobile Satellite Service Systems, FCC 16-181, REPORT AND ORDER, __ FCC Rcd. __ (rel. December 23, 2016).

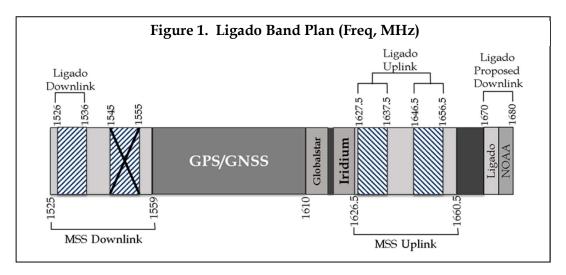
Ligado Networks, Advancing Next-Generation Connections for Tomorrow: Ligado Networks Market Vision (available at: http://ligado.com/wp-content/uploads/Ligado_MarketVision.pdf).

See Harbinger Order, supra n. 12. Significantly, this transaction was not voted on by the full Commission, but approved by various bureau chiefs on delegated authority. Moreover, the order included a "voluntary commitment" at the last minute that amounted to a *de facto* spectrum cap on the two largest CMRS providers, even though the affected parties had not no meaningful opportunity for notice and comment. For a detailed case study of the *Harbinger Order*, see, e.g., T.R. Beard, G.S. Ford, L.J. Spiwak, and M. Stern, *Eroding the Rule of Law: Regulation as Cooperative Bargaining at the FCC*, PHOENIX CENTER POLICY PAPER NO. 49 (October 2015) (available at: http://www.phoenix-center.org/pcpp/PCPP49Final.pdf).

concerns, so the company's efforts serve as a meaningful case study of how interference problems influence, or should influence, spectrum repurposing.

A. Ligado's Proposed Repurposing

While additional spectrum for mobile broadband use is a policy priority, and other licensees in the MSS band have received approval to modify their ATCs,17 Ligado's request for ATC modification – initially filed under the LightSquared brand in 2010 – has been held up for years due to interference concerns.¹⁸ Figure 1 illustrates the source of the interference problem.



In its current proposal, Ligado intends to use 20 MHz of downlinks at 1526-1536 MHz and 1670-1680 MHz and 20 MHz of uplinks at 1627.5-1637.5 MHz and 1646.5-1656.5 MHz. In its original proposal (as LightSquared), the block at 1545-1555 MHz block was intended as a downlink, but this block was within a few MHz of spectrum used for GPS services and, as such, raised significant interference concerns. Anxious for more spectrum for mobile broadband

See supra n. 14.

LightSquared Subsidiary LLC Request for Modification of its Authority for an Ancillary Terrestrial Component, SAT-MOD-20101118-00239 (filed Nov. 18, 2010). LightSquared was granted a conditional waiver requiring it resolve interference complaints, which LightSquared never did and the Commission initial waiver was suspended. Request for Modification of its Authority for an Ancillary Terrestrial Components, ORDER AND AUTHORIZATION, SAT-MOD-20101118-00239 (Rel. January 26, 2011) (available at: http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-11-133A1.pdf); Statement from FCC Spokesperson Tammy Sun on Letter from NTIA Addressing Harmful Interference Testing Conclusions Pertaining to LightSquared and Global Positioning Systems, Federal Communications Commission (February 14, 2012) (available at: https://apps.fcc.gov/edocs_public/attachmatch/DOC-312479A1.pdf).

service, the FCC initially overlooked the potential interference problem, but other federal agencies were not blinded with the same enthusiasm.¹⁹ The Federal Aviation Administration ("FAA") and the NTIA, for instance, expressed concern that Ligado's network would interfere with its high-precision GPS receivers, thereby threatening the safety and efficiency of air travel, stranding billions of dollars in FAA and GPS investments, and requiring a retrofit of all airplanes.²⁰ Private providers of GPS services also alerted the Commission of interference problems. For example, the GPS community stated that it was

... concerned because testing has shown LightSquared's ground-based transmissions overpower the relatively faint GPS L1 signals from space. Although LightSquared would operate in its own authorized band, the band is so close to the GPS signals that many GPS devices could pick up the stronger LightSquared signals and become overloaded or saturated. There is also concern that millions of existing GPS users could be forced to upgrade their devices and/or accept GPS performance losses to accommodate the new network.²¹

¹⁹ See, e.g., February 14, 2012 Letter from Lawrence E. Strickling to Chairman Julius Genachowski (available at: http://www.ntia.doc.gov/files/ntia/publications/lightsquared_letter_to_chairman_genachowski_-_feb_14_2012.pdf); February 14, 2012 Statement From FCC Spokesperson Tammy Sun on Letter From NTIA Addressing Harmful Interference Testing Conclusions Pertaining to LightSquared and Global Positioning Systems (available at: https://apps.fcc.gov/edocs_public/attachmatch/DOC-312479A1.pdf) ("NTIA, the federal agency that coordinates spectrum uses for the military and other federal government entities, has now concluded that there is no practical way to mitigate potential interference at this time. Consequently, the Commission will not lift the prohibition on LightSquared."); D. Meyer, FCC Denies LightSquared's Access to Spectrum, RCRWIRELESS (February 15, 2012) (available at: http://www.rcrwireless.com/20120215/carriers/fcc-denies-lightsquareds-access-to-spectrum). See also Grassley Continues Scrutiny of FCC on LightSquared, Lifts Holds on FCC Nominees, Office of Chuck Grassley, U.S. Senator for Iowa (April 27, 2012) ("news reports showed the White House pressured a four-star general to downplay the threat LightSquared posed to GPS") (http://www.grassley.senate.gov/news/news-releases/grassley-continues-scrutinyfcc-lightsquared-lifts-holds-fcc-nominees).

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²⁰ FAA: LightSquared Not Compatible With Aviation, GIM International (July 28, 2011) (available at: https://www.gim-international.com/content/news/faa-lightsquared-not-compatible-with-aviation); LightSquared, Industry Agree: Signals Would Interfere With GPS, National Business Aviation Association (July 13, 2011) (available https://www.nbaa.org/ops/cns/gps/interference/20110713-lightsquared-signals-would-interfere-withgps.php); J. Smith, Aviation, GPS Representatives Warn of LightSquared's "Catastrophic" Plans, NATIONAL JOURNAL (February 8, 2012) (available at: https://www.yahoo.com/news/aviation-gps-representatives-warn-lightsquaredscatastrophic-plans-135437424.html).

²¹ LightSquared and GPS, GPS.gov, National Coordination Office for Space-Based Positioning, Navigation, and Timing (available at: http://www.gps.gov/spectrum/lightsquared).

A government study of LightSquared's proposal supported these concerns. As for the proposed downlink operations in the 1545-1555 MHz band, the NTIA concluded,

Based on NTIA's independent evaluation of the testing and analysis performed over the last several months, we conclude that LightSquared's proposed mobile broadband network will impact GPS services and that there is no practical way to mitigate the potential interference at this time.²²

Faced with resistance from federal agencies and the private sector, the Commission's International Bureau was forced to delay approval of LightSquared's request. As such, the International Bureau required the establishment of a working group to resolve these interference concerns before Ligado could commence service.²³ As a result of the delay, LightSquared entered bankruptcy.

In December 2015, Ligado emerged from bankruptcy with a new plan.²⁴ Among other accommodations, Ligado proposed to abandon its authority for terrestrial operations in the 1545-1555 MHz portion of the MSS downlink band, and to operate in three other L-band segments — base stations in the 1526-1536 MHz portion of the MSS downlink band and user equipment in the 1627.5-1637.5 MHz and 1646.5-1656.5 MHz portions of the MSS uplink band—under a more restrictive set of operational parameters (a combined set of power limits and OOBE limits) than currently authorized. Ligado asserted that its abandonment of the use of the 1545-1555 MHz portion of the MSS L-band downlinks (as illustrated in Figure 1) for terrestrial operations addresses a critical concern of the GPS industry, and that when considered with other features of the proposal, GPS receivers are in effect provided a "significant guard band" from terrestrial services. In addition, to protect certified aviation GPS devices, Ligado proposed that its license be conditioned on power limitation requirements for operation in the 1526-1536 MHz band as necessary to achieve compatibility with current and future Minimum Operational Performance Standards that are incorporated into an active Technical Standard Order from the Federal Aviation Administration.

As a replacement for the 1545-1555 MHz block, Ligado proposes to shift its downlink operations to the 1670-1680 MHz block. Ligado is not the licensee for the replacement band but

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Letter from Lawrence E. Strickling to Chairman Julius Genachowski, *supra* n. 19.

²³ In the Matter of LightSquared Subsidiary LLC, Request for Modification of its Authority for an Ancillary Terrestrial Component, SAT-MOD-20101118-00239, Call Sign: S2358, DA 11-133, 26 FCC Rcd. 566, ORDER AND AUTHORIZATION (rel. January 26, 2011) (hereinafter "LightSquared ATC Order").

²⁴ See Public Notice: Comment Sought on Ligado's Modification Applications, IB Docket No. 11-109; IB Docket No. 12-340, DA 16-442, 31 FCC Rcd. 3802 (April 22, 2016) at 5-6.

has an arrangement with Crown Castle (the licensee) to lease the 1670-1675 MHz block, already licensed for terrestrial use.²⁵ As for the remainder, Ligado proposed to share the 1675-1680 MHz block with the National Oceanic and Atmospheric Administration ("NOAA"), but "only if coordinated to protect government systems that will remain in the band, including weather monitoring and predicting operations of the National Oceanic and Atmospheric Administration (NOAA) that operate under primary allocations in the band for Meteorological Aids and the Meteorological Satellite Service."²⁶ In Ligado's view, these accommodations will finally allow it to bring 40 MHz of purported "greenfield" mid-band spectrum to market, producing significant public interest benefits.²⁷ The FCC put Ligado's amended application out for public notice and comment on April 22, 2016.²⁸

By combining technical changes to its proposal and making financial accommodations to members of the GPS community, Ligado's new plan appears to have satisfied certain segments of the GPS industry.²⁹ Ligado reached an agreement with some large GPS users including Deere, Garmin and Trimble.³⁰ Subsequent to the close of the pleading cycle of this docket, Ligado's counsel filed a letter with the Commission notifying the agency that it had reached a cooperation agreement with a fourth GPS provider—Topcom.³¹ However, the fact that Ligado may have reached deals with several GPS providers does not mean that all of the interference concerns with

²⁵ See Public Notice: Wireless Telecommunications Bureau Seeks Comment on Request by OP LLC for Extension or Waiver of the Construction Deadline Concerning Its 1670-1675 MHz Band License, DA 12-1776, 27 FCC Rcd. 13524 (rel. November 05, 2012)

²⁶ Comment Sought to Update the Record on Ligado's Request that the Commission Initiate a Rulemaking to Allocate the 1675-1680 MHz Band for Terrestrial Mobile Use Shared with Federal Use, Public Notice, RM-11681 (April 22, 2016) at p. 2 (available at: https://apps.fcc.gov/edocs-public/attachmatch/DA-16-443A1.pdf); see also Ligado Comments, In re Comment Sought on Ligado's Applications, IB Docket No. 11-109 (May 23, 2016) at pp. 1, 8-10.

²⁷ See Ligado Comments, id. passim. In support of their argument, Ligado submitted a declaration by Dr. Coleman Bazelon of the Brattle Group. See C. Bazelon, Putting Mid-Band Spectrum to Work: Sharing between Ligado Networks and its GPS Neighbors (May 23, 2016).

²⁸ Supra n. 24.

P. Fitzgerald, New LightSquared Settles GPS Lawsuit With Garmin, WALL STREET JOURNAL (December 17, 2015) (available at: https://www.wsj.com/articles/new-lightsquared-settles-gps-lawsuit-with-garmin-1450363420); P. Fitzgerald, LightSquared and Deere Settle GPS Spectrum Lawsuit, WALL STREET JOURNAL (December 8, 2015) (available at: https://www.wsj.com/articles/lightsquared-and-deere-settle-gps-spectrum-lawsuit-1449610672); LightSquared ex parte filing, IB Dockets 12-340, 11-109, at 1 n.1, December 31, 2015 ex parte filing.

³⁰ Ligado Says Testing Shows that LTE Network Won't Interfere with GPS, TRDAILY (February 27, 2016) (available at: https://blog.npstc.org/2016/02/27/ligado-says-testing-shows-that-lte-network-wont-interfere-with-gps).

³¹ See November 29, 2016 Letter from Doug Smith and Ivan D. Federico, IB Docket No. 11-109 et seq. (available at: https://ecfsapi.fcc.gov/file/12062186417510/FCC%20Letter%20TopconLigado.pdf).

GPS users were resolved. For example, a number of users who heavily rely upon GPS services have expressed continued concern about interference, including several major airlines, general aviation enthusiasts as well as major aerospace and defense manufacturers.³²

Despite this activity, it is important to recognize that Ligado still has relatively small business operations as of this writing. In particular, in 2013, LightSquared reported that it provided satellite services to at least fifteen wholesale partners who in turn provided service to approximately 300,000 subscribers in North America.³³ Ligado is currently providing its satellite service to the United States through two satellites, Skyterra-1 and MSAT-2. Skyterra-1 was launched in 2010 and provides the bulk of Ligado's customer services and is authorized to operate on 23 MHz of spectrum.³⁴ MSAT-2 was launched in 1995 and provides some customer service but largely serves as a backup for Skyterra-1.³⁵ MSAT-2 is authorized to operate on 28 MHz of

See, e.g., Comments of Aircraft Owners and Pilots Association, Airlines for America, Aviation Spectrum Resources, Inc., Bristow U.S., LLC, Cargo Airline Association, Delta Airlines, Helicopter Association International, International Air Transport Association, National Air Transportation Association, Rockwell Collins IMS, Southwest Airlines, and United Parcel Service (the "Joint Aviation Parties"), IB Docket No. 11-109 et seq. (filed May 23, 2016) at i ("There remain too many unresolved issues to alleviate the aviation sector's concerns that Ligado's proposed operations will present an unacceptable threat of harmful interference to the aviation GPS receivers."); Comments of the Aerospace Industries Association, IB Docket No. 11-109 et seg. (filed May 23, 2016) at p. 1 ("As explained below, it would be premature to grant the Applications at this time, as there are substantial concerns regarding the adequacy of the proposed conditions to protect the GPS receivers and other avionics used by the aerospace and defense industries, including but not limited to certified aviation receivers, other GPS devices, and satellite communications."); Comments of Airlines for America, IB Docket No. 11-109 et seq. (filed May 23, 2016) at p. 3 ("Specifically, we urge the Federal Communications Commission (FCC) to delay action on the Ligado proposals because serious safety questions must first be resolved."); Letter from Nikolaos Papadopoulos, President of u-blox America, Inc., to FCC Secretary, IB Docket No. 11-109 et seq. (filed May 20, 2016) at p. 1 ("We have a major concern that the receivers out in the field will be affected by the Ligado signals close to L1 band as they are from our receiver point-of-view in-band interference, especially where no SAW-filtering is used in the devices."); Letter from Timothy St. J. Ellam, Counsel to NovAtel Inc., to Marlene H. Dortch, FCC Secretary, IB Docket No. 11-109 et seq. (filed May 19, 2016) at p. 4 ("NovAtel submits that the foregoing concerns with respect to potential harmful interference to GPS receivers have not yet been addressed by Ligado and represent a legitimate and ongoing concern should Ligado operate a terrestrial mobile network in the referenced MSS L-band frequencies.").

Notice of Filing by Ad Hoc LP Secured Group of Solicitation Versions of First Amended Plan and Disclosure Statement, LightSquared, Inc., *et al.*, Debtors, Chapter 11, Case No. 12-12080 (SCC), U.S. Bankruptcy Court, S.D.N.Y. (filed Oct. 28, 2013).

³⁴ Skyterra-1 is authorized to operate on 1525-1544 MHz & 1545-1559 MH (downlink) and 1626.5-1545.5 & 1646.5-1660.5 (uplink).

MSAT-2's original authorization expired in 2010 and Ligado has obtained annual FCC approval to extend that authorization since then. In January 2017, Ligado let its MSAT-2 license authorization lapse and filed with the FCC's International Bureau to request reinstatement of its license. Ligado plans to deorbit this satellite at the end of 2017.

uplink and downlink spectrum.³⁶ Ligado is providing service over a combined 51 MHz of spectrum in the United States. Taking the 300,000 end users from 2013, Ligado is serving 5,882 customers per one MHz of spectrum. However, it was reported just as this BULLETIN was being released that Ligado has hired investment bank Goldman Sachs to explore strategic alternatives (either sale or additional investment), but it is unclear whether it will find any takers due to its large debt load and investor fears over full debt repayment.³⁷

B. Additional Interference Issues

Ligado's filings at the FCC suggest the company believes that its resolution of GPS interference (at least among some service providers) satisfies the company's requirements to address interference.³⁸ However, there are other significant parties challenging Ligado's band plan due to out-of-band emissions ("OOBE"). For instance, as shown in Figure 1, Ligado intends to operate a download link by sharing the 1675-1680 MHz band with NOAA. NOAA and the meteorological community, however, are opposed to the proposal.

1. Sharing NOAA's Spectrum

The World Meteorological Organization ("WMO"), for instance, claims that Ligado's proposal will interfere, if not block outright, the use of weather satellites for "warning of natural and environmental disasters and detailed understanding of the status of global water resources."³⁹ The WMO is also concerned that FCC-determined protections will only be afforded

(Application to extend MSAT-2 license term through 2017, Ligado Networks Subsidiary LLC, IBFS File No. SAT-MOD-20170112-0003 (filed Jan. 12, 2017).

 $^{^{36}}$ MSAT-2 is authorized to operate on 1530-1544 MHz & 1545-1559 MHz (downlink) 1631.5-1645.5 MHz & 1646.5-1660.5 (uplink).

³⁷ L. Baker, Exclusive: Ligado Networks Hires Banks to Explore Options – Sources, REUTERS (March 13, 2016) (available at: http://www.reuters.com/article/us-ligadonetworks-m-a-idUSKBN16K2GR).

³⁸ See e.g., Ligado Comments in Docket No. 11-109 (May 23, 2016) at p. 13 (the Co-Existence Agreements, and the resulting modifications proposed in the Modification Applications, with GPS providers "represent the sum total of all the concerns raised by the major GPS manufacturers" and, as such, "constitutes a comprehensive solution for the entire GPS industry." Thus, according to Ligado, "the entire GPS industry is better off from the certainty these Co-Existence Agreements do, and approval of the Modification Applications would, provide.") (Emphasis supplied.)

³⁹ WMO Comment in Opposition to RM-11681, World Meteorological Organization (June 21, 2016) (available at: https://ecfsapi.fcc.gov/file/107201312917147/16071403-9.pdf); Ligado's 1675-1680 MHz Band Petition Panned by Users of NOAA Data, National Public Safety Telecommunications Council (June 28, 2016) (https://blog.npstc.org/2016/06/28/ligados-1675-1680-mhz-band-petition-panned-by-users-of-noaa-data).

U.S.-based satellite stations, thereby leaving international stations at risk.⁴⁰ Ligado contests the interference claims of the meteorological community and proposes that those using NOAA services have the option of terrestrial-based alternatives such as the Internet.⁴¹ The WMO responds that such alternatives are not sufficiently reliable for such important information and for all users.⁴² At present, the disagreement between Ligado and the meteorological community remains unresolved and appears to be increasingly adversarial in nature.⁴³

There are other complainants regarding the sharing of NOAA's spectrum. A coalition of aviation interests, for instance, claim, "Ligado's current proposal to develop exclusion zones for Ligado base stations only around certain Federal [NOAA] sites is flawed and requires further study through a multi-stakeholder process." The Florida Department of Transportation also has commented, stating it "objects to permitting Ligado to share this band for terrestrial mobile service due to the risk of interference."

2. Iridium Communications

Figure 1 reveals another potential victim of Ligado's plan—Iridium Communications. Iridium operates the world's largest commercial constellation of 66 non-geostationary orbital cross-linked satellites (and nine ground spares) with 850,000 customers world-wide and annual revenues exceeding \$400 million, providing global coverage and offers fixed and mobile satellite communications services.⁴⁶ Iridium is in the process of a \$3 billion, 70 satellite upgrade to its network—Iridium NEXT—which began launching in the first quarter of 2017.⁴⁷ The company is an established MSS provider, one of two providers, which sells mission-critical MSS services and

⁴⁰ WMO Comment, id.

⁴¹ P. Kirby, *Ligado Responds to Concerns about 1675-1680 MHz Sharing*, TRDAILY (August 12, 2015) (available at: https://blog.npstc.org/2016/08/24/ligado-responds-to-concerns-about-1675-1680-mhz-sharing).

WMO Comments, supra n. 39.

⁴³ Kirby, supra n. 41.

⁴⁴ August 11, 2016 Reply Comments of Aviation Spectrum Resources Inc., *et al.* in RM-11-11681 (available at: https://ecfsapi.fcc.gov/file/1081211620678/Joint%20Aviation%20Reply%20Comments%208%2011%202016.pdf).

July 20, 2016 Reply Comments of the Florida Department of Transportation in RM-11681 (available at: https://ecfsapi.fcc.gov/file/1072020498400/ligado%20reply%20comments%20160619.docx).

⁴⁶ Iridium Communications, Annual Report (2016) (available at: http://investor.iridium.com/secfiling.cfm?filingID=1564590-17-2101&CIK=1418819) at p. 3.

⁴⁷ See, e.g., A. Pasztor and R. Winkler, SpaceX Resumes Rocket Launches by Lofting Cluster of Iridium Satellites, Wall Street Journal (January 16, 2017) (available at: http://www.wsj.com/articles/spacex-resumes-rocket-launches-by-lofting-cluster-of-iridium-satellites-1484417292).

equipment to consumers, public and private, and to the U.S. Department of Defense, the company's largest customer.⁴⁸ At the heart of Iridium's network is its licensed access to an unpaired portion of the L-band which it uses for both uplink and downlink operations.⁴⁹ Iridium operates as an exclusive user of the 1618.725-1625.5 MHz band, while the company shares the 1617.775-1618.725 MHz band with Globalstar's Big LEO system.⁵⁰

In its filings, Iridium states "Ligado's proposed terrestrial operations would generate excessive out-of-band emissions, causing interference with the operations of Iridium in the adjacent spectrum band,"⁵¹ and that the "potentially millions of 5G mobile devices transmitting just 1 MHz away from the spectrum that Iridium uses for all of its critical uplink and downlink services" will cause significant harm to Iridium's adjacent-band terminals.⁵² As with the sharing of NOAA's spectrum, the dispute between Ligado and Iridium remains open and is becoming increasingly adversarial as Ligado seeks approval to modify its ATC from the Commission.

3. Summary of Interference Disputes

We have not provided an exhaustive list of the interference claims brought against Ligado. Moreover, evaluating the legitimacy of the interference claims is beyond the scope of this BULLETIN. Parties filed rival engineering reports with the Commission and we direct interested parties to study those filings.⁵³ We have no interest in choosing sides among participants in these

⁴⁸ Iridium Annual Report, *supra* n. 46 at p. 5.

⁴⁹ See Comments of Iridium Networks, Ligado Networks LLC, Application to Modify its Ancillary Terrestrial Component Authorization, IB Docket Nos. 11-109, IB Docket No. 12-340 (May 23, 2016) (available at https://ecfsapi.fcc.gov/file/60002015571.pdf) at 3-4. Specifically, Iridium is licensed to use 8.725 MHz of spectrum between 1616 and 1626.5 MHz (exclusive use of the 1618.725 MHz to 1626.5 MHz band and shared use of the 1617.775 to 1618.725 MHz band). See In the Matter of Spectrum and Service Rules for Ancillary Terrestrial Components in the 1.6/2.4 GHz Big LEO Bands; Review of the Spectrum Sharing Plan Among Non-Geostationary Satellite Orbit Mobile Satellite Service Systems in the 1.6/2.4 GHz Bands, Second Order on Reconsideration, Second Report & Order, and Notice of Proposed Rulemaking, 22 FCC Rcd. 19733, 19752 ¶ 43 (2007), aff d sub nom. Globalstar, Inc. v. FCC, 564 F.3d 476 (D.C. Cir. 2009).

⁵⁰ See Letter from Bryan Tramont on Behalf of Iridium Communications (December 14, 2016) (available at: https://ecfsapi.fcc.gov/file/121415807018/Iridium%20response%20to%20Ligado%20technical%20analysis%2012.14. 16.pdf) at p. 8. As a shared user, Iridium must tolerate interference from Globalstar.

⁵¹ *Id.* at p. 1.

⁵² Reply Comments of Iridium Networks, *Ligado Networks LLC, Application to Modify its Ancillary Terrestrial Component Authorization,* IB Docket Nos. 11-109, IB Docket No. 12-340 (June 21, 2016) at 9-11 (available at https://ecfsapi.fcc.gov/file/10621295714013/Iridium%20Reply%20Comments.pdf).

⁵³ See, e.g., Technical Analysis of Ligado Interference Impact on Iridium User Links (Sept. 1, 2016) ("Iridium Technical Analysis") (attached to Letter from Bryan N. Tramont, Counsel, Iridium, to Marlene H. Dortch, Secretary,

ongoing disputes. The fact that such disputes exist and are ongoing is sufficient to motivate our analysis, which is no way is specific to Ligado's woes. Our intent is to provide an economic framework for analyzing such disputes whether they arise from repurposings proposed by the NTIA, incorporated in secondary market transactions by active and established players, or part of more speculative efforts as in Ligado's case.

III. Commission Rules on Interference in the MSS Band

With wireless communications, interference is always a concern. The Commission has numerous rules and procedures addressing interference. Since Ligado's proposed modification is in the MSS band, Ligado's request falls under the Commission's rules at Section 25.255, which states:

If harmful interference is caused to other services by ancillary MSS ATC operations, either from ATC base stations or mobile terminals, the MSS ATC operator must resolve any such interference. If the MSS ATC operator claims to have resolved the interference and other operators claim that interference has not been resolved, then the parties to the dispute may petition the Commission for a resolution of their claims.⁵⁴

The Agency's rule is quite clear: since the ATC is a modification to the license, it is up to Ligado to "resolve any [] interference concerns" to other services caused by its ancillary ATC operations. The rules appear to prefer the relevant private and in some cases public parties to resolve these matters. As already mentioned, with regard to Ligado's GPS problems, the company has done much to minimize concerns, going as far as to abandon its proposed downlink operations at the 1545-1555 MHz block. A few large GPS providers no longer challenge Ligado's proposal, though some resistance remains.

Ligado's filings to the Commission indicate it believes it has provided a "comprehensive solution" to the interference problems, at least for the GPS industry. Yet, as mentioned above, a number of parties continue to challenge Ligado's plan based on lingering interference concerns, even in the GPS band. Ligado has expressed a "continued commitment to working with the staff

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FCC, IB Docket Nos. 11-109 and 12-340 (filed Sept. 1, 2016)); Letter from Gerard J. Waldron. Counsel to Ligado, to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340 (filed Nov. 2, 2016) ("Ligado Technical Analysis"); Letter from Bryan N. Tramont, Counsel to Iridium, to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 and 12-340 (filed Dec. 14, 2016) (Iridium response); Technical Analysis of Ligado Interference Impact on Iridium Aviation Services (December 14, 2016) (available at: https://ecfsapi.fcc.gov/file/12140004709937/Iridium%20Aviation%20Technical%20Analysis%20-%20Public%20Redacted.pdf).

⁵⁴ 47 C.F.R. § 25.255.

and all stakeholders that this process can move forward to conclusion," so the possibility of additional deals is ever present.

Whether or not successful negotiations are forthcoming is unknowable, but the rising adversarial nature of the process makes the prospect for private solutions to all remaining disputes look grim. The FCC may have to play a more active and direct role in resolving lingering disputes. In fact, the Commission must approve Ligado's plan for the company to begin its terrestrial operations, based upon an unlikely finding that Ligado has resolved its interference problems. However, if interference disputes arise once Ligado (or the buyer of its spectrum) begins service, then the victims may, under § 25.255, appeal to the Commission for resolution of an actual and active interference problem.⁵⁵

Delaying resolution is risky, however, as the realization of interference subsequent to approval causes real economic harm. Plainly, to the greatest feasible extent, minimizing the risk of such harm prior to approval is ideal. If interference issues arise after Commission approval, then an interesting question is which of the potential victims of interference should the Commission prioritize for resolution? That is, is there some basis for the Commission to treat different entities differently in its *ex ante* resolution of lingering interference concerns. We argue the answer is "yes" by demonstrating that the optimal interference policy rewards protection to victims of interference based on the magnitude of the victim's sunk costs in telecommunications network.

No matter how the Ligado petition plays out, what is clear, at least to us, is that the legal mechanisms governing interference disputes—formal or otherwise—will play an important role in the evolution of the wireless marketplace, affecting the quantity and type of spectrum repurposed, the pace of the process, the incentives to invest in wireless networks, and the value of spectrum itself. If the Commission eventually resolves itself the remaining interference disputes, then it should proceed with an understanding of the economic consequences of its actions. With that in mind, we now present an economic analysis of repurposing spectrum in the presence of interference concerns.

IV. Economic Model

In reviewing public policy advocacy for mobile wireless services, one quickly realizes that spectrum is king and there never seems to be enough of it. But despite the intense attention spectrum receives in policy discussions, spectrum licenses do not produce any benefits by themselves. Rather, any benefits obtained arise solely from the willingness of public and private

55 *Id*.

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parties, primarily the license holders, to make often large, and largely sunk, capital investments in the equipment necessary to produce communications services using spectrum.⁵⁶ The willingness to make the large sunk investments in communications equipment depends on the extent to which spectrum repurposing imposes new and unforeseen technical burdens on incumbent license holders due to the interference. The incentives to make such investments also depend both on their sunkeness, and on the extent to which some sort of "accommodation" or mitigation is available when and if interference arises due to some allowed repurposing. Such "accommodation" can take various forms including technical rules or financial consideration, and it can be based on various criteria.

In the analysis below, we consider the incentives of a licensee to make sunk investments in a wireless network when the licensee faces the positive probability that an interfering use of an adjacent band may occur in the future. This interference reduces the licensee's revenue stream, harms profitability, and in turn reduces the incentive to invest in the equipment necessary to turn spectrum into valuable communications services. The role of the regulator is to determine the level of accommodation to the victim of interference. By "accommodation", we do not necessary mean monetary payments; accommodation may include some technical remedy that reduces the damage caused by the interference.

A. Formal Analysis

To begin, suppose that Firm A owns a license to a block of spectrum (e.g., Iridium). The firm can make a costly investment x that, combined with the spectrum, can generate a revenue V(x). We will generally assume that V(x) is an increasing and concave function of investment.⁵⁷ That is, revenues rise with investment but at a diminishing rate (i.e., diminishing marginal returns).

Now, suppose that Firm B (e.g., Ligado) owns the license of an adjacent block of spectrum and wants to repurpose it, but this new use poses an interference risk to Firm A's block. Let θ represent the exogenous probability that such a repurposing occurs and that it would diminish the value V derived from the spectrum investment of Firm A by the fraction δ . That is, the licensee—Firm A—realizes that, with some probability, she may face a degradation in the revenue flow generated by her sunk investment x, and we represent the severity of this effect by δ . For instance, Firm A may believe there is a 50% probability (θ = 0.50) that a repurposing occurs, and this repurposing would reduce Firm A's revenue flow by 20% (δ = 0.20).

⁵⁶ See generally, T.R. Beard, G.S. Ford, L.J. Spiwak and M. Stern, Wireless Competition Under Spectrum Exhaust, 65 FEDERAL COMMUNICATIONS LAW JOURNAL 79 (2012) (available at: http://www.phoenix-center.org/FCLJSpectrumExhaust.pdf).

⁵⁷ So that V'(x) > 0 and V''(x) < 0.

In light of § 25.255 of the Commission rules, the Agency apparently prefers private solutions to interference disputes arising from ancillary terrestrial uses of the MSS band. Consequently, Firm B is required to resolve the interference problem in private negotiations with Firm A, the victim. But, if an agreement cannot be reached, then the Commission may find itself in a determinative role. Let z represent the accommodation (or mitigation), determined by the Commission, which the harmed firm would receive in this circumstance. A complete absence of protective rules (or inaction by the regulatory authority) would imply that z was zero. With some mechanism for protecting licensee holders, z would be positive and expected to reflect the magnitude of the harm. It is easiest to think of z as monetary accommodation, but "accommodation" may represent technical solutions such as power limitations or guard bands. For instance, in negotiating with the GPS industry, Ligado used a mixture of technical solutions and financial compensation. Practically speaking, one can imagine many bases on which z might be determined.

For our purposes, the critical issue is the role of sunk investments, x, in determining the accommodation obtained by the spectrum licensee suffering from interference (Firm A). Here, we illustrate the fundamental point that the expected profitability of the investment can be altered by altering z – the level of accommodation. As we demonstrate, maintaining investment incentives requires that z be an increasing function of investment x. We show that when z is *not* a function of the level of sunk costs x, then the level of z will *not* affect the investment chosen by the firm.

The mathematics makes this point clear. Assuming zero marginal cost (so that revenue equals gross profit), the expected profit of the licensee (π) making sunk investment x is:

$$\pi(x) = \theta[(1 - \delta)V(x) + z] + (1 - \theta)V(x) - x. \tag{1}$$

The first term on the right-hand side is equal to the net revenue of Firm A after the repurposing that occurs with probability θ , reduces revenues by the factor δ , and includes accommodation/mitigation level z. The second-term is the profitability of Firm A if there is no repurposing, which occurs with probability $(1 - \theta)$. Whether the repurposing occurs or not, profits are realized only when an investment, x, is made (the last term of Expression 1).

Firm A maximizes its profits by choosing the level of sunk investment. Maximizing $\pi(x)$ with respect to x, we obtain:

⁵⁸ See supra n. 29.

$$\theta(1-\delta)V'(x^*) + \theta \frac{\partial z}{\partial x} + (1-\theta)V'(x^*) = 1;$$
 (2)

where Expression (2) characterizes the privately optimal level of firm investment x^* , assuming Algebraic manipulation of Expression (2) yields a more useful this amount is positive. expression,

$$V'(x^*) = \frac{1 - \theta \frac{\partial z}{\partial x}}{1 - \theta \delta} . \tag{3}$$

Due to the concavity of V(x), the derivative V'(x) will be a decreasing function of x. Our interest is in the relationship between sunk costs (x) and accommodation (z), a term that appears in the numerator (i.e., $\partial z/\partial x$).

If the firm does not perceive that the accommodation z will be linked to the investments that it has made (i.e., $\partial z/\partial x = 0$), then Expression (3) implies that the firm's optimal investment x^* would be a decreasing function of θ .⁵⁹ That is, if the regulator's accommodation level z is not related to investments, then the greater the probability an interference-causing repurposing occurs, the less licensees will invest in their networks. In effect, Firm A hedges its investment for fear of the regulatory permitting interference-causing repurposings.

If, however, spectrum policy and practice create the belief that z will be an increasing function of the investments that have been made $(\partial z/\partial x > 0)$, then the negative impacts of potential repurposings that lead to interference, with probability θ , can be mitigated. For example, if $\partial z/\partial x = \delta$ so that the level of accommodation equals the reduction in profit, then $V'(x^*) = 1$, and the firm's optimal investment would no longer be a function of θ . In such a case, repurposings may occur without fear of attenuating investment incentives.

Our analysis demonstrates that if spectrum value and investment levels are to be insulated from interference as the spectrum deck gets reshuffled, then license holders facing financial damage due to the interference caused by adjacent band repurposing should receive accommodation-either monetary or in the form of technical restraints-which is tied to the magnitude of their sunk investments. The Commission, then, must deal with different license holders differently, and this differential treatment is based on the extent their sunk investments in networks making use of their spectrum licenses vary. License holders who have made little or no sunk investment in capital to produce marketable services-whether speculators or government agencies - would receive little relief under an optimal rule. Those licensees with

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The right-hand side simplifies to $1/(1 - \theta \delta)$, which clearly shrinks as θ gets larger.

substantial sunk investments would receive far more expansive treatment by the Commission in regards to interference.

We expect that in the coming years the NTIA and the FCC will be repurposing a great deal of spectrum. The actions of these federal agencies on interference will establish precedent that incumbent spectrum licensees will incorporate into their investment decisions. If interference-causing repurposings are permitted and the significant sunk assets to provide services using spectrum are given short shrift, then the rational response of private parties is to curb investment. A reduction in investment will reduce the value of wireless services and, in turn, the value of the spectrum. Furthermore, consumers are frequently required to make sunk investments in wireless technologies to use the services of their providers. If consumers sense that these personal investments may be stranded by federal policy, then consumers will reduce their personal investments and the value of the wireless sector will decline. So, while federal agencies must repurpose spectrum to create value, they also must avoid destroying value through the unartful management of interference.

B. Market Solutions

Since § 25.255 appears to encourage spectrum licensees and users to resolve interference concerns in private negotiations, we have some interest in whether or not private negotiations would also reflect the sunk costs of victims. If so, then our policy prescription is consistent with the market outcomes preferred by the Commission's rule.

To evaluate the private negotiation, consider a Nash Bargain between two parties—Firm A (the victim) and Firm B (the perpetrator)—involved in an interference-causing spectrum repurposing. Let G denote the benefit generated for Firm B if the repurposing is allowed. For the repurposing to occur, Firm B must address the interference to Firm A, which is accomplished by a mutual agreement on accommodation (z) in order to move forward with the repurposing. A Nash Bargain over the accommodation level z would solve:

$$\max_{z} \{ [G - z] [(1 - \delta)V(x) + z - V(x)] \}, \text{ or, more simply,}$$
 (4)

$$\max_{z} \{ [G-z][z-\delta V(x)] \}. \tag{5}$$

Hence, $z^*(x) = \frac{1}{2} (G + \delta V(x))$. Notice that the mutual agreement rule creates the expectation that sunk investments are positively correlated with the accommodation:

$$\frac{\partial z^*}{\partial x} = \frac{1}{2} \delta V'(x) > 0. \tag{6}$$

Incorporating this expression into Equation (3), we have

$$V'(x^*) = \frac{1}{1 - \frac{1}{2}\theta\delta} \ . \tag{7}$$

Compared to the case where the accommodation is uncorrelated with investments, the magnitude of $V'(x^*)$ is smaller. Since V'(x) is a decreasing function, the magnitude of x^* would be larger. Thus, the level of accommodation from a private negotiation also reflects the victim's level of sunk cost. As our model above prescribes, the level of accommodation will vary among victims by their sunk costs and, in doing so, offsets, at least in part, the negative impact that repurposing risk could have on sunk investments in communications plant.

C. No Agreement

As discussed above, § 25.255 directs spectrum licensees to resolve interference concerns in private negotiations. Any time parties attempt to negotiate an accommodation, the outcome of that negotiation may very well be no agreement at all. In our model, the optimal accommodation is $z^*(x) = \frac{1}{2} (G + \delta V(x))$. If the gain to Firm B from the repurposing of its licenses (G) is less than the harm caused to Firm A (the victim) of the resulting inference (δV), then no bargain is reachable and the victim simply walks away from the negotiating table. Importantly, a failure of parties to reach an accommodation does not indicate a market failure requiring government intervention. Under the mandate of § 25.255, the FCC must exercise care that its authority over spectrum is not used merely to circumvent a market outcome based on relative costs and benefits of the parties involved.

D. Welfare Analysis

To lament a reduction in investment, we must first believe that investment was too low to start with. We are on safe ground. In general, the expectation is that private firms will have an inadequate incentive to make sunk investments of the sort considered here, so investment is, from a total welfare perspective, usually too low. Although our technical analysis above is necessarily greatly simplified and of a partial-equilibrium form, as a first approximation we take the relevant welfare level for analysis to be the sum of firm profits and consumers' surplus. Investment by the firm will maximize profits of course, and will ignore consumers' surplus. However, by analogy, investment in capacity is similar in effect to an output increase, and output increases result in lower prices and thus higher consumer benefits. This implies that the investment level selected by the firm is less than that which maximizes the sum of profits and consumers' surplus, other things equal.

E. The Value of Spectrum

We argue above that it is the investment in communications infrastructure, not spectrum values, that should be the focus of the regulator in resolving interference disputes. It is

investments, usually large and sunk, that create value. Nevertheless, the FCC is understandably interested in the consequences of repurposing rules for the value of spectrum licenses, since a portion of such value is often extracted by the federal government as auction proceeds. The willingness to pay of potential buyers is inextricably tied to the presence and nature of any rules restricting the use of spectrum licenses, including rules impeding the ability to repurpose the spectrum to a more profitable use.⁶⁰

Somewhat less obviously, such restrictions on spectrum use can actually increase willingness to pay for licenses when there is interference between the uses of "adjacent" pieces of property. If license holders were permitted to repurpose spectrum at will, then incumbent licensees in adjacent bands must account for the risk of having the performance of their networks materially degraded by the use of nearby frequencies for new and possibly "noisy" purposes. Buyers are less willing to pay for spectrum licenses when the purchase involves onerous conditions, including restrictions on repurposing the spectrum to more valuable, yet unforeseen, uses. It is in the interests of both the potential buyer and society that profitable innovations are allowed to flourish. However, it is also difficult to forecast what these innovations may involve, or what impact they could have on the technical landscape. Rigidity in repurposing rules for spectrum use may deprive us of the benefits of important innovations. Thus, technical restrictions on the repurposing of spectrum have two conflicting effects on the potential buyer. First, such restrictions may foreclose future profit opportunities, thus lowering willingness to pay. Second, such restrictions protect profits derived from the property if they prevent other users from degrading its value by engaging in activities that cause radio interference. Thus, the repurposing decision can be quite complex.

We suggest here that an important and hitherto overlooked point arises when addressing interference. That is, in order to avoid reducing willingness to pay for spectrum licenses (possibly affecting auction revenues), one need only compensate license holders for losses of revenues or profits. If, for instance, interference reduces the value of an adjacent spectrum license by \$1 million, then providing accommodation to the license holder in that amount leaves her whole,

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⁶⁰ See, e.g., G.S. Ford, T.M. Koutsky and L.J. Spiwak, Using Auction Results to Forecast the Impact of Wireless Carterfone Regulation on Wireless Networks, Phoenix Center Policy Bulletin No. 20 (Second Edition) (May 2008) (available at: http://phoenix-center.org/PolicyBulletin/PCPB20Final2ndEdition.pdf); G.S. Ford and L.J. Spiwak, Auction 97 and the Value of Spectrum, Phoenix Center Policy Perspective No. 15-02 (February 4, 2015) (available at: http://phoenix-center.org/perspectives/Perspective15-02Final.pdf); G. Madden, I. Saglam, and I. Hussain, Spectrum Auction Designs and Revenue Variations, 47 Applied Economics 1748-1763 (2015); G. Madden and H. Suenaga, The Determinants of Price in 3G Spectrum Auctions, Applied Economics (December 2016) (available at: http://www.tandfonline.com/doi/full/10.1080/00036846.2016.1254342?scroll=top&needAccess=true); G.S. Ford and M. Stern, Ugly is Only Skin Deep: An Analysis of the DE Program in Auction 97, Phoenix Center Policy Perspective No. 15-04 (July 20, 2015) (available at: http://phoenix-center.org/perspectives/Perspective5-04Final.pdf).

thus mitigating her reduction in willingness-to-pay. However, such accommodation does not generally solve the challenge of promoting investment by the license holder. As we demonstrate above, regulators must tie accommodation to the level of the victim's sunk investments to maintain investment incentives.

F. Application to Ligado's Plan

Our analysis demonstrates that an optimal policy deals with different license holders differently according to their sunk investments. License holders who have made little or no sunk investment to deploy the equipment necessary to generate benefits from their spectrum holdings (e.g., speculators) would receive little relief under an optimal rule.⁶¹ On the other hand, licensees who have made substantial sunk investments in capital would receive far more expansive treatment.

Much of Ligado's efforts have focused on resolving interference disputes with the GPS sector. At present, the GPS industry relies on 24 satellites in middle earth orbit. Certainly, these satellites represent significant sunk investments (by the Department of Defense) in communications network facilities. In addition, significant sunk investments have been made by a variety of GPS users, including the FAA and the airlines. Some of those criticizing Ligado's proposal may not have made significant sunk commitments to GPS services, and these users should, by our theory, receive less "accommodation" from the Agency. Some users of the NOAA spectrum may likewise have committed little in the way of sunk investment.

We note, however, that we do not model directly the investments made by end users, though we recognize such investments are critical to the value created by a communications network. If interference from repurposings were to strand such investments, then users would likewise attenuate their investments. Still, end-user investments in consumer-grade equipment may be small and short-lived (e.g., GPS receivers and watches), and that may weaken the case for high accommodation. Investments in airplanes, military equipment, base stations, and some other technologies, however, are long-lived and often expensive, so the federal government's attention to the GPS, meteorological, and other impacted sectors is certainly justifiable based on our analysis. Considering end-user investments would certainly be a natural extension of this work.

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⁶¹ By its very definition, spectrum speculation is a risky business. *See* Beard, *et al.*, *supra* n. 3. Indeed, the fact that a speculator pays a significant amount of money for spectrum is no guarantee that the Commission must grant a request for repurposing. The Commission's authority over radio spectrum under Title III is absolute and, as such, the Commission is under no obligation to find a request for spectrum repurposing to be in the public interest in the face of significant interference concerns. *See*, *e.g.*, 47 U.S.C. § 316. Thus, the potential to bet on the wrong horse is very real.

Iridium Communications is perhaps the best example of the type of victim our theory speaks to. Few capital assets are more sunk than are satellites, of which Iridium has over 70 and plans to launch 70 more. Iridium carries \$2.4 billion in property, plant and equipment on its balance sheet, and will invest about \$3 billion more in its new system.⁶² Plainly, Iridium has made substantial sunk investments—specific to its frequency bands—in the billions of dollars, has plans to invest billions more, and provides mission-critical communications services to both the private, public, and military sectors. Iridium is no speculator—it is an ongoing and important communications business and has proven to be an ideal steward of spectrum resources. Iridium claims that it is the process of negotiating with Ligado in the hopes of reaching an accommodation similar to that reached with GPS providers, and Iridium claims that 47 C.F.R. § 25.255, the burden is on Ligado to resolve these interference concerns.⁶³ If such negotiations fail, then Iridium, by nature of its sunk investments, should receive significant "accommodation" by the Commission before the Agency allows Ligado, or whomever acquires its spectrum subsequent to the Commission's approval, to commence service.⁶⁴

We stress, however, that the most critical economic and legal issue is not the fate of Iridium (or any other party) *per se.* Rather, how the Commission decides to treat Iridium in this proceeding will establish a precedent for future cases involving interference and sunk costs. As our economic analysis shows, it is advisable for the Commission to consider the sunk investments of private firms like Iridium and public-players like the Department of Defense in its determination of the proper accommodation/mitigation for interference. A failure to do so risks a general discouragement of the sunk investments needed to realize the social benefits of radio spectrum. If, for instance, Iridium's business plan is materially harmed by interference resulting from Ligado's repurposing, or even if Iridium's concerns are given short-shrift by the Commission, then we suspect the policy decision will have a chilling effect on investment in wireless communications networks generally. In many respects, Iridium and other victims of Ligado's interference serve as a "canary in the coal mine" during this period of substantial spectrum repurposings, signaling to existing spectrum licensees how the Commission will address interference and investments during this period of substantial repurposing of spectrum.

V. Conclusion

As more and more spectrum is repurposed from low- to high-valued uses, interference concerns are likely to grow. In this BULLETIN, we contemplate how public policy can support

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⁶² Iridium Communications, Annual Report, *supra* n. 46 at p. 66.

⁶³ Iridium Comments, supra n. 49 at p. 2.

⁶⁴ *Id.* at 13-14, *citing* 47 C.F.R. § 25.255 ("If harmful interference is caused to other services by ancillary MSS ATC operations, either from ATC base stations or mobile terminals, the MSS ATC operator must resolve any such interference.")

investment incentives by spectrum licensees (or their agents) in the presence of an interference threat caused by a repurposing of spectrum. This analysis provides a nuanced and, we hope, useful contribution to the important problem of repurposing licensed property such as radio spectrum when auction revenue is important, sunk investments are necessary to realize the benefits of licensed property, and technical interference between property uses is a concern.

Our analysis sheds light on the optimal design of Commission rules and practices for addressing interference disputes. Analyzing the scenario where an existing licensee faces a positive probability of a profit-reducing, interference-inducing repurposing, we find that to maintain investment incentives in communications equipment—equipment necessary for radio spectrum to create any value—the Commission's optimal interference policy would treat different license holders differently according to their sunk network investments. License holders who have made little or no sunk investment in capital to generate benefits from their license would receive little relief under an optimal rule. Licensees with substantial sunk network investments, however, would receive far more expansive treatment by the regulator. Such a policy need not undermine the flexibility necessary for new, very-high value innovations to be launched. Barring antitrust or similar concerns, voluntary agreement between the affected licensees should assure that the resulting outcome is a welfare improvement.