Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

	)	
In the Matter of	)	
	)	IB Docket No. 11-109
Comment Sought on Ligado's Modification Applications	)	

To: The Commission

COMMENTS OF LIGADO NETWORKS LLC

Gerard J. Waldron
Michael Beder
Dustin Cho
Ani Gevorkian
COVINGTON & BURLING LLP
One CityCenter
850 Tenth Street, NW
Washington, DC 20001
(202) 662-6000

Counsel for Ligado Networks LLC

May 23, 2016

Contents

I. Introduction and Summary 1

II. Terrestrial Use of Ligado's Mid-Band Spectrum Will Promote 5G and Serve the Public Interest 5

A. Adding Mid-Band Spectrum Will Enhance the Mobile Industry's Ability to Meet Growing Demand and Lead the Global Transition to 5G and IoT. 5

B. Commission Action to Enable Use of Mid-Band Spectrum Will Generate Billions in Consumer Benefits. 7

III. Terrestrial Use of Mid-Band Spectrum at the Reduced Levels in the Modification Applications Will Cause No Actual Harm to GPS Devices 9

A. LightSquared's 2010 Spectrum Proposal Raised Issues with Adjacent GPS Devices that Resulted in FCC Action and Bankruptcy. 9

B. The Power and OOBE Levels Now Proposed by Ligado Protect GPS Devices from Actual Harm. 11

1. The Co-Existence Agreements Establish, and RAA's Empirical Results Confirm, that Ligado's Proposal Protects GPS. 11

2. Measuring Key Performance Indicators is the Appropriate Method to Determine Whether Ligado's Proposed Operations Would Cause Harmful Interference. 24

C. The Proposed Power and OOBE Limits Will Address GPS Concerns. 27

IV. The Proposed Condition on the Lower Downlink Band Promotes Safety and Results in Ongoing Compliance with FAA's Safety Requirements 29

CONCLUSION 33

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Comment Sought on Ligado's Modification Applications	)	IB Docket No. 11-109
	)	

To: The Commission

COMMENTS OF LIGADO NETWORKS LLC

I. INTRODUCTION AND SUMMARY

Approval of Ligado Networks LLC's ("Ligado") proposed license modifications serves the public interest because the vital mid-band spectrum that is covered by the licenses will accelerate the wireless industry's deployment of next-generation mobile connectivity and 5G technology, an essential step to maintaining American leadership in the wireless economy.[1] This mid-band spectrum in the 1-2 GHz range, which presents a "greenfield" opportunity for the wireless sector, will be an important complement to the low-band spectrum being auctioned now; together they will enable the wireless industry to deliver innovative Internet of Things ("IoT") solutions and also support the robust technology development and network deployment of 5G in the United States. Allowing this mid-band spectrum to finally be deployed for terrestrial use will generate at least $250 billion to $500 billion in social welfare benefits by advancing the wireless economy, promoting productivity in the work place and in everyday life, and encouraging innovation by entrepreneurs across nearly every industry sector.

---

[1] *See* IBFS File Nos. SAT-MOD-20151231-00090, SAT-MOD-20151231-00091, and SES-MOD-20151231-00981 (collectively, "Modification Applications"). The Modification Applications include a "Description of Proposed Modification and Public Interest Statement" (Modification Applications, Description of Proposed Modification).

Approval of the Modification Applications also will provide benefits to other important stakeholders, most notably the GPS community. As the Commission observes in its Public Notice,[2] approval of the Modification Applications will create a protective new guard band for the GPS industry, establishing a 23 megahertz guard band to the left of the GPS signal as a result of Ligado's relinquishment of terrestrial authorization for the band closest to the GPS allocation.[3] Affording even more protection to GPS device manufacturers and consumers, Ligado proposes substantially reduced power limits in the bands to the left and right of the GPS spectrum block, in addition to out-of-band-emission ("OOBE") limits (reduced by a factor that ranges from 10 to 800) from the uplink bands to the right of the GPS spectrum block. The reduction in power level between the parameters Ligado's predecessor sought in 2010 and the parameters proposed in the Modification Applications is dramatic: the difference between a stadium floodlight and a night light. These reduced operational parameters stem from co-existence agreements that Ligado reached with the three largest GPS device companies: Deere & Company ("Deere"), Garmin International, Inc. ("Garmin"), and Trimble Navigation Limited ("Trimble"). These reduced power and OOBE limits led those companies to not oppose Ligado's deployment and operation of a terrestrial network in the subject bands.[4] Moreover,

---

[2] *Comment Sought on Ligado's Modification Applications*, IB Docket Nos. 11-109 & 12-340, DA 16-442 (April 22, 2016) ("Public Notice").

[3] The guard band would be 23 megahertz conservatively measuring from the edge of Ligado's downlink to the edge of the GNSS band. Measuring from center frequency to center frequency, the guard band is as much as 44 megahertz.

[4] *See* Letter from Gerard J. Waldron, Counsel to New LightSquared LLC, to Marlene H. Dortch, Secretary, FCC, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SAT-MOD-20101118-00239; SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; SES-RWL-20110908-01047; SES-MOD-20141030-00835, at 4 (Dec. 8, 2015) ("December 8 Ex Parte"); Letter from Gerard J. Waldron, Counsel to New LightSquared LLC, to Marlene H. Dortch, Secretary, FCC, IB Docket No. 12- 340; IB Docket No. 11-109; IBFS File Nos. SAT-MOD-20101118-00239; SAT-MOD-20120928- 00160; SAT-MOD-20120928-00161; (continued…)

approval of the Modification Applications will cement these benefits for the entire GPS industry and their customers.

Approval of the Modification Applications also is in the public interest because, as the record shows, these reduced power limits will cause Ligado's network to be invisible, inaudible, and non-existent to consumer GPS devices such as smartphones and general navigation devices. This fact clearly could be deduced from the Co-Existence Agreements reached with each of the three major GPS manufacturers shortly after the company exited bankruptcy. LightSquared emerged from bankruptcy as a new company with new owners, a new board of directors, and a new approach to pursuing its proposed operations, and almost immediately reached these agreements. Those agreements reflect the judgment of each of those GPS companies, operating independently, as to what was needed to protect their GPS devices. Each of the GPS manufacturers did its own analysis and formed its own conclusion as to what reductions in power and OOBE limits they required. Those restrictions were then written into the Co-Existence Agreements, which require that Ligado request modifications of its licenses in accordance with those restrictions, as Ligado has done in the instant Modification Applications.

The fact that the Co-Existence Agreements reflect an operational level that protects GPS consumer devices has been corroborated by evidence put on the record earlier this month in response to the Public Notice's request for specific data.[5] The test program that Roberson and Associates ("RAA") completed verifies that Ligado's proposed utilization of the spectrum

---

SES-MOD-20121001-00872; SES-RWL-20110908-01047; SES-MOD-20141030-00835, at 25 (Dec. 17, 2015) ("December 17 Ex Parte"); Letter from Gerard J. Waldron, Counsel to New LightSquared LLC, to Marlene H. Dortch, Secretary, FCC, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SES-MOD- 20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091, at 4, 7, 19 (Feb. 3, 2016) ("February 3 Ex Parte").

[5] Public Notice at 7-8.

assigned to it for terrestrial use is compatible with existing GPS operations as implemented by leading device manufacturers.[6] Specifically, the RAA data confirms that if the Modification Applications are granted, the Co-Existence Agreements do indeed ensure that consumers' GPS-equipped devices will not experience actual harm as defined by the Commission and will perform as the manufacturers warranted.[7] The RAA study further confirms that, for certain industrial uses, some GPS devices are designed in such a way that they already co-exist with Ligado's proposed network, while other devices will not be used near any network facility or can be replaced or retrofitted cost effectively well before Ligado's network would begin operation.[8]

The proposed license modifications also require Ligado to operate in a manner that is consistent with all FAA requirements applicable to certified aviation GPS devices, as set out in the FAA's Technical Standards Orders. This proposed license condition recognizes the vital role the FAA and the aviation industry must play in protecting aviation safety. This approach is consistent with Commission licensing arrangements in the L-band and in other bands requiring coordination, thus preserving the Commission's role as Ligado's regulator while nevertheless also ensuring a vital role for the FAA and the aviation industry.

In summary, the Commission should find that the Modification Applications promote the public interest by advancing the President's goal of adding this vital national resource of radio spectrum to the public use and enjoyment, and by doing so in a way that actually provides a long-sought guard band and other regulatory protections to the GPS industry and its consumers,

---

[6] *See* Roberson and Associates, LLC, "Results of GPS and Adjacent Band Co-Existence Study," IB Docket No. 11-109, at 2 (filed May 11, 2016) ("Roberson Results Report").

[7] *Id*. at 11-12.

[8] *Id*. at 12-13.

and does so in a manner that ensures GPS devices, including certified aviation devices, will be fully protected.

II. TERRESTRIAL USE OF LIGADO'S MID-BAND SPECTRUM WILL PROMOTE 5G AND SERVE THE PUBLIC INTEREST

The Modification Applications present the Commission with a rare opportunity to unlock a greenfield of mid-band spectrum that can fill a vital role in the future of next-generation wireless networks, including 5G. Demand for spectrum is enormous, and will increase as IoT further develops and expands. To meet that pressing demand and to pave the way for 5G, it is essential that spectrum is put to its most efficient uses. The Modification Applications do precisely that. Granting the Modification Applications will provide additional mobile network capacity that is urgently needed and will provide at least $250 billion to $500 billion in social welfare benefits.[9] Moreover, efficient use of spectrum requires different frequencies to be deployed in ways that reflect their comparative advantages, and Ligado expects to maximize both the characteristics of its mid-band spectrum and its existing satellite system by developing differentiated network capabilities ideally suited for a key category of 5G use-cases.

A. Adding Mid-Band Spectrum Will Enhance the Mobile Industry's Ability to Meet Growing Demand and Lead the Global Transition to 5G and IoT.

Chairman Wheeler has emphasized that "American leadership in 5G is a national priority."[10] Leadership in 5G requires efficient use of mid-band spectrum as a critical component of America's 5G future — and in particular, greenfield mid-band spectrum, which

[9] *See* Coleman Bazelon, *Putting Spectrum to Work: Sharing Between Ligado Networks and Its GPS Neighbors*, at 1 (May 23, 2016) (hereinafter, "Bazelon Report"). The total social value of wireless broadband spectrum is estimated to be at least 10 to 20 times the direct economic value of the spectrum, and therefore approximately $250 billion to $500 billion of social welfare will be created by granting the Modification Applications. *Id*. at 9.

[10] Remarks of FCC Chairman Tom Wheeler, INCOMPAS Policy Summit, April 11, 2016, *available at* https://apps.fcc.gov/edocs_public/attachmatch/DOC-338806A1.pdf.

has the potential to provide capacity and flexibility for the growing demand in next-generation IoT. Indeed, a range of emerging IoT applications would be best served by mid-band spectrum's reliability and suitability for high-quality coverage deployment. Mid-band spectrum is ideal for these use cases because, unlike very high-frequency spectrum, these frequency bands have better propagation characteristics, and thereby better support in-building penetration and economical coverage deployment. The nationwide license of Ligado's mid-band spectrum also promotes operational efficiencies in the design, manufacture, and deployment of equipment, thereby accelerating the earlier adoption of 5G at very economical cost. Moreover, the capacity and spectrum characteristics of the mid-band spectrum will complement the low-band spectrum that is being made available through the Incentive Auction by enabling collaboration that takes advantage of both bands. Granting the Modification Applications would promote 5G because Ligado's proposal is directly aligned with making possible these efficient uses of mid-band spectrum as part of the next generation of mobile networks.[11]

Ligado expects to offer capabilities and services to and with the wireless industry that make full use of the unique advantages of mid-band spectrum. Relative to existing mobile carriers, which are expected to prioritize enhanced mobile broadband services for traditional devices such as phones and tablets, Ligado will focus on next-generation network capabilities that will be particularly attractive to "mission-critical" IoT use cases. In particular, Ligado expects its network will be capable of providing:

- **pervasive connectivity** covering North America by leveraging its hybrid satellite and terrestrial services;
- **ultra-reliability** for improved remote monitoring, emergency response, and public safety use;

[11] *See* Bazelon Report, *supra* note 9, at 1.

- **enhanced precision location services** that support centimeter-level accuracy; and
- **highly secure transmissions**, by taking advantage of its design to reduce vulnerabilities inherent in other network architectures.

By supporting emerging IoT applications, Ligado's plan would accelerate the enablement of the growing next-generation IoT market and further promote American leadership in 5G.[12]

B. Commission Action to Enable Use of Mid-Band Spectrum Will Generate Billions in Consumer Benefits.

In addition to fostering 5G and the tremendous potential benefits that the next generation of mobile connectivity has to offer, the Modification Applications will create between $250 billion and $500 billion of social welfare simply by alleviating enormous pent-up demand for wireless broadband service, which is currently the highest valued commercial use of spectrum.[13] As the Commission's National Broadband Plan observed, "broadband is a foundation for economic growth, job creation, global competitiveness and a better way of life."[14] While mobile broadband's reliability and data rates have been improving from 3G to 4G (and will take another leap forward with 5G), the bandwidth burden on network providers has grown exponentially and wireless networks are straining to meet the demand.[15] In addition to increasing innovation for

---

[12] *Id.* at 5-8.

[13] *Id.* at 5, 8-9. The total social value of wireless broadband spectrum is estimated to be at least 10 to 20 times the direct economic value of the spectrum, and therefore approximately $250 billion to $500 billion of social welfare will be created by granting the Modification Applications. *Id*. at 8-9.

[14] FCC, *Connecting America: The National Broadband Plan* xi (2009), *available at* http://www.broadband.gov/plan/.

[15] Bazelon Report, *supra* note 9, at 6-8, 10-11, 14; *see Protecting and Promoting the Open Internet*, R&O on Remand, Declaratory Ruling, and Order, 30 FCC Rcd 5601, 5636 (2015) ("As a consequence of the growing deployment of next generation networks, there has been an increase of more than 200,000 percent in the number of LTE subscribers, from approximately 70,000 in 2010 to over 140 million in 2014. Concurrent with these substantial changes in mobile broadband deployment and download speeds, mobile data traffic has exploded, increasing from 388 billion MB in 2010 to 3.23 trillion MB in 2013.").

new consumer devices, Ligado's proposal to add terrestrial use L-band spectrum will provide additional mobile capacity, promote competitive offerings and innovations by wireless providers, and enhance public safety and homeland security services.[16] By contrast, if the Modification Applications are not approved, 40 MHz of mid-band spectrum will continue to lie fallow, essentially imposing an opportunity-cost on society equivalent to $250 billion to $500 billion.

The total social benefit associated with activating a greenfield for wireless broadband is enormous.[17] Broadband spectrum generates immense social value in the broader economy: Every dollar spent on wireless service results in the spending of more than two dollars in the economy, and every job in the wireless industry creates several jobs elsewhere.[18] Furthermore, Ligado's spectrum will play a part in helping America take the lead on 5G and next-generation IoT, the full economic impact of which will reach between $3.9 trillion and $11.1 trillion by 2025 — the vast majority of which will be captured by customers.[19] These huge public benefits associated with the Modification Applications make it clear that the public interest overwhelmingly favors approving the Modification Applications. In the meantime, for so long as this valuable mid-band spectrum is left in limbo, the country forgoes the acceleration effects that wireless broadband capacity has to offer, and which would otherwise be rippling through the economy.

Importantly, because the Applications' power limits and OOBE limits protect the GPS industry (as explained in more detail in the next section of these Comments), approving the Applications without imposing further power restrictions would maximize these social welfare

---

[16] Bazelon Report, *supra* note 9, at 7.

[17] *Id.* at 6-8.

[18] *Id.* at 8-9.

[19] *Id.* at 12.

benefits.[20] The major costs of transitioning the L-band for terrestrial use, as proposed by Ligado, will be borne by Ligado. Accordingly, the Applications are an opportunity for Pareto improvement: Society stands to gain without anyone losing.[21] Any more restrictive power or OOBE limits than those proposed in the Applications therefore would cause unnecessary harm and would needlessly reduce the benefits to society that flexible L-band spectrum use has to offer.[22]

III. TERRESTRIAL USE OF MID-BAND SPECTRUM AT THE REDUCED LEVELS IN THE MODIFICATION APPLICATIONS WILL CAUSE NO ACTUAL HARM TO GPS DEVICES

Since emerging out of a prolonged bankruptcy, Ligado has vigorously sought solutions that would enable the company to put its critical mid-band spectrum to its most productive use. These efforts have borne fruit, in the form of Co-Existence Agreements with the leading GPS manufacturers that set the parameters under which Ligado can operate its proposed terrestrial network without objection from the leading GPS companies. The data collected by RAA confirms that these parameters — which, through the modifications sought in the Modification Applications, would benefit the entire GPS industry — effectively protect GPS.

A. LightSquared's 2010 Spectrum Proposal Raised Issues with Adjacent GPS Devices that Resulted in FCC Action and Bankruptcy.

Ligado's current licenses (which were previously held by LightSquared prior to its bankruptcy and reorganization) include an authorization to provide ancillary terrestrial component ("ATC") mobile service using portions of the frequency bands in which Ligado is

[20] *Id.* at 16.

[21] *Id.*at 17.

[22] *Id.*

licensed to provide mobile satellite service.[23] However, in response to concerns that were raised regarding the compatibility of LightSquared's proposed terrestrial mobile network with GPS operations in the 1559-1610 MHz band, the International Bureau in 2011 established a multi-stakeholder testing process — which included the participation of the National Telecommunications and Information Administration ("NTIA") as well as the GPS industry and LightSquared — to analyze and address potential interference concerns.[24] Ultimately, after considering technical studies organized by that group and additional studies and analysis submitted by NTIA, the International Bureau sought comment in 2012 on whether LightSquared's ATC authorization should be suspended indefinitely.[25] LightSquared opposed such suspension, while GPS industry commenters continued to object to LightSquared's proposed mobile operations based on concerns that those operations would interfere with GPS operations.[26]

Although the Commission never formally acted on the proposed suspension, LightSquared and certain of its affiliates were forced to seek Chapter 11 bankruptcy, filing petitions for relief on May 14, 2012. Bankruptcy proceedings lasted more than three years. On March 27, 2015, the U.S. Bankruptcy Court approved a reorganization plan, and on December 3, 2015, the Commission approved the assignment of licenses and international section 214

---

[23] *LightSquared Subsidiary LLC Request for Modification of its Authority for an Ancillary Terrestrial Component*, Order and Authorization, 26 FCC Rcd 566 (IB 2011) ("*2011 Order*").

[24] *2011 Order*, 26 FCC Rcd at 587.

[25] *International Bureau Invites Comment on NTIA Letter Regarding LightSquared Conditional Waiver*, Public Notice, 27 FCC Rcd 1596, 1599 (IB 2012).

[26] *See*, *e.g.*, Comments of the U.S. GPS Industry Council, IB Docket 11-109 (filed March 16, 2012); Comments of Deere & Company, IB Docket No. 11-109 (filed Mar. 16, 2012).

authorizations and the transfer of domestic section 214 authority to the reorganized LightSquared.[27]

On December 7, 2015, after more than three years in bankruptcy, LightSquared emerged as a new company with new owners, a new board of directors, and a new approach to pursuing its proposed operations. The company, now known as Ligado Networks, stands ready, willing, and able to address legitimate issues and put to use its vital mid-band spectrum to benefit the American consumer. Given the wireless industry's evolution over the past several years toward the establishment of 5G and the growth of IoT, Ligado's proposed mobile network operations would serve the public interest more now than ever before.

Accordingly, Ligado's current proposal aims both to resolve the concerns raised in 2012 and also to promote the public interest by enabling additional spectrum to be used for next-generation mobile services. To this end, in the Modification Applications, Ligado has offered a comprehensive solution to the concerns raised by the GPS industry and has established a clear and achievable path to proceed with the deployment of its next generation mobile network.

B. The Power and OOBE Levels Now Proposed by Ligado Protect GPS Devices from Actual Harm.

1. The Co-Existence Agreements Establish, and RAA's Empirical Results Confirm, that Ligado's Proposal Protects GPS.

The proposed power and OOBE limits under which Ligado now seeks authorization to operate its terrestrial network are designed to ensure that GPS devices experience no actual harm. The substantially reduced power and OOBE limits in the Modification Applications derive from two sources: 1) the Co-Existence agreements Ligado reached with the major GPS

[27] *See Application of LightSquared Subsidiary LLC, Debtor-in-Possession, and LightSquared Subsidiary LLC*, Mem. Op. & Order and Declaratory Ruling, 30 FCC Rcd 13988, 13988-90 (2015).

device manufacturers, and 2) RAA's testing and assessment of how Ligado's terrestrial deployment will affect GPS devices at various power and OOBE levels. These proposed limitations form the key elements of the pending Modification Applications. The RAA data, discussed below, verifies that the limitations proposed by the major GPS manufacturers do in fact protect GPS devices.

The Co-Existence Agreements with Deere, Garmin, and Trimble

Shortly following its emergence from bankruptcy, Ligado reached separate understandings with each of Deere, Garmin, and Trimble — three of the leading GPS device companies.[28] Each of these agreements (collectively, the "Co-Existence Agreements") sets forth the operating parameters under which Ligado could operate without objection from the relevant GPS company.

Specifically, in their respective agreements, Deere and Garmin agreed that they will not object to Ligado's terrestrial deployment in three of the four bands licensed to Ligado — the 1526-1536 MHz, 1627.5-1637.5 MHz, and 1646.5-1656.5 MHz frequency bands — as long as Ligado operates under certain power and OOBE limits. The Garmin agreement does not address potential interference concerns relating to certified aviation devices, which are addressed separately below. Trimble also agreed not to object to Ligado's proposed operations in two of those three bands — the 1627.5-1637.5 MHz and 1646.5-1656.5 MHz frequency bands. Regarding operations in the lower downlink band (1526-1536 MHz), the Trimble agreement allows for further analysis of terrestrial use of that band. The specifications set forth in the three Co-Existence Agreements determine the parameters under which Ligado now seeks to operate.

[28] *See supra* note 4.

It bears emphasis that in negotiating these agreements, each of the GPS companies bargained for the specific parameters and commitments required for the continued successful operation of its own GPS devices. Thus, the Co-Existence Agreements, and the resulting modifications proposed in the Modification Applications, reflect the distinct needs of each company's devices, use cases, and market share. Significant differences existed among each of those companies' needs. Ligado was not able to take a short cut to resolution by agreeing simply to one GPS company's requirements. Rather, Ligado worked diligently to comprehensively address the requirements unique to each of the three companies. In that regard, the Modification Applications represent the sum total of all the concerns raised by the major GPS manufacturers.

Such an effort was worthwhile, not only because it addressed the concerns of the three leading GPS device companies, but also because the collective result of the negotiations constitutes a comprehensive solution for the entire GPS industry. Although each of Deere, Garmin, and Trimble have particular operational needs, addressing the needs of Deere, Garmin, and Trimble goes a long way toward addressing the needs of the GPS industry as a whole because, aside from cellular devices, the receiver designs used by Deere, Garmin, and Trimble use are also used by, and feed into, the larger GPS ecosystem and supply chain.[29] Accordingly, the entire GPS industry is better off from the certainty these Co-Existence Agreements do, and approval of the Modification Applications would, provide.

Ligado had in mind the beneficial ripple effects agreements with Deere, Garmin, and Trimble would produce — which is in part why Ligado endeavored to reach those agreements.

---

[29] Bazelon Report, *supra* note 9, at 31; Letter from Gerard J. Waldron, Counsel to Ligado Networks LLC, to Marlene S. Dortch, Secretary, FCC, RM-11681, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SES-MOD- 20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091, Declaration of Bill Alberth at 2 ¶ 6 (Feb. 11, 2016) ("February 11 Ex Parte").

Ligado was well aware that these three companies are industry leaders. Garmin supplies 84 percent of the personal navigation device ("PND") market, the largest subset of devices in the consumer-facing general location and navigation ("GLN") device market.[30] Other GPS device manufacturers generally purchase the components for their devices off the shelf from the same suppliers from which Garmin purchases components for its devices, and thus the agreement Ligado reached with Garmin will benefit the broader consumer GPS industry.[31] In the high-precision space, Trimble and Deere play an equally important role. Together, they represent 51 percent of the high precision device market.[32] Ligado thus sought to account for the needs of all players in the GPS industry, demonstrating the new company's commitment to identifying and solving specific problems. In addition, the Co-Existence Agreements were designed to fully protect the interest of GPS consumers, demonstrating Ligado's commitment to ensuring that consumers are not harmed by Ligado's terrestrial deployment.[33]

In essence, the reduced power and OOBE limits in the Co-Existence Agreements are a form of unilateral disarmament, in which Ligado has agreed to forgo terrestrial authorization for ten megahertz of spectrum and operate with substantially reduced power limits on the other bands. Specifically, *Ligado has agreed to operate at power limits that are lower than its current licenses authorize by a factor of 10 times for the downlink and a factor of five times for the uplinks, and for the first five years, by as much as a factor of 1,250 times for part of the uplink closest to the GPS band.* Ligado also has agreed to operate with out-of-band-emission limits that

[30] Bazelon Report, *supra* note 9, at app'x 1 tbls. 5 & 9.

[31] February 11 Ex Parte, *supra* note 29, Declaration of Bill Alberth at 3 ¶ 9.

[32] Bazelon Report, *supra* note 9, at app'x 1 tbl. 9.

[33] This effort is ongoing. The company continues to engage in discussions with GPS device manufacturers to address specific issues they may have.

are lower than what is currently authorized by a factor that ranges from 10 times to 800 times from the uplink bands into the GPS spectrum band. Ligado recognizes that its operational plans will need to be consistent with the Co-Existence Agreements, but Ligado assumes these obligations willingly for the sake of protecting GPS, bringing this spectrum into productive use, and acting in the public interest.

Ligado's Assessment of its Network Deployment and Co-Existence with GPS Devices

The empirical data collected by RAA and submitted earlier this month to the docket confirms that the parameters agreed to in the Co-Existence Agreements and embodied in Ligado's Modification Applications effectively protect GPS operations. RAA was engaged in June 2015 to advise on spectrum interference issues and also to conduct tests on how deployment of LTE operated at various power levels would affect the performance of GPS devices. As this research and assessment unfolded, RAA shared with Ligado preliminary data on how LTE at various power levels affected the position error of GPS devices.[34] This information led Ligado to assess its operational and business plans in light of substantially reduced power and OOBE levels.[35] It also helped Ligado understand the operational parameters that would enable LTE and GPS devices to co-exist.[36] Thus, the power limits and OOBE limits the GPS companies proposed during discussions related to the Co-Existence Agreements were consistent with Ligado's understanding, since the preliminary RAA data had suggested the GPS companies would require those parameters.

[34] Declaration of Scott Wiener at ¶ 4.

[35] *Id*. at ¶ 5.

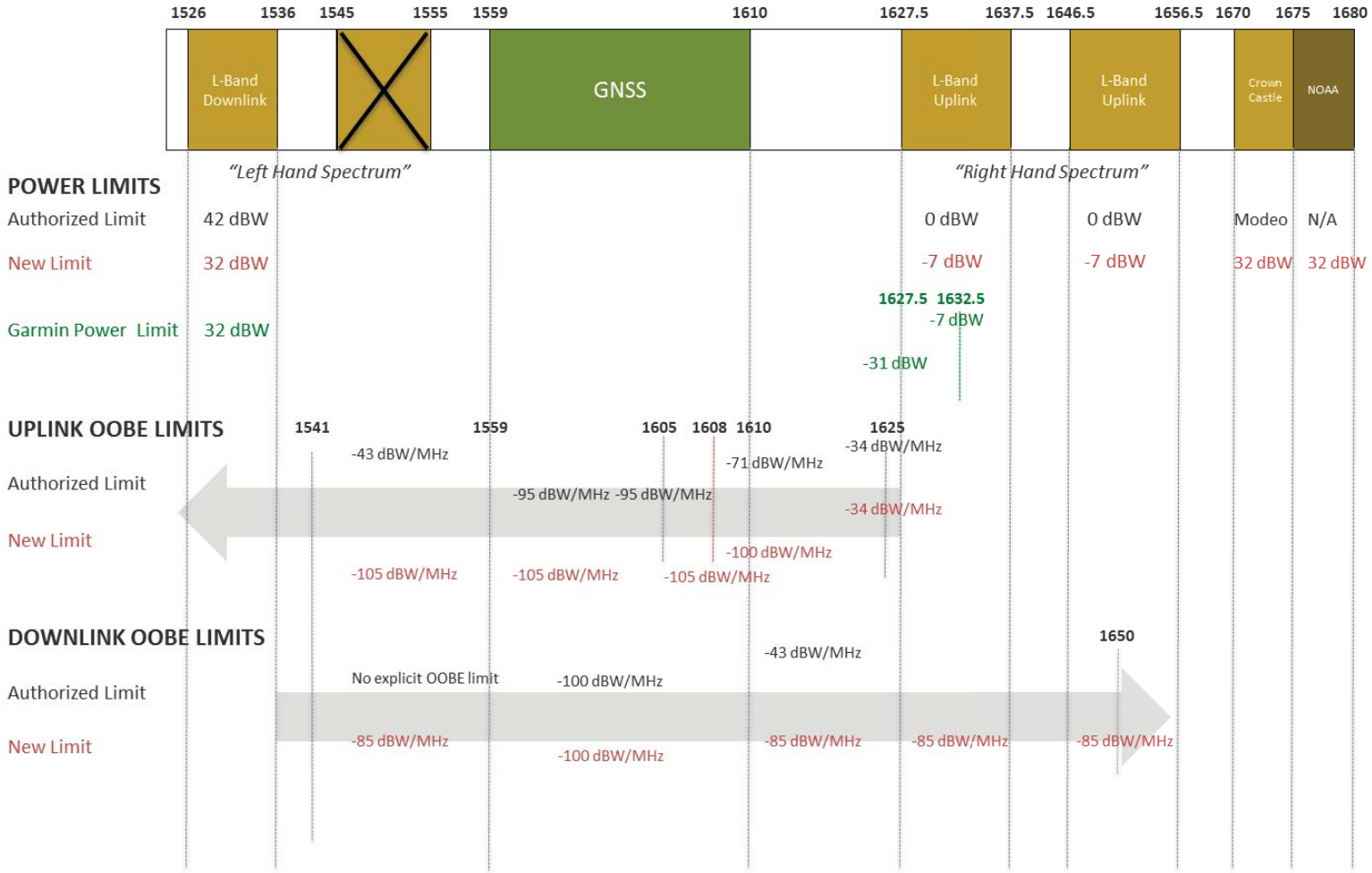
[36] *Id*. at ¶ 6.

The December 31, 2015 Modification Applications

On December 31, 2015, in fulfillment of specific requirements in the Co-Existence Agreements, Ligado submitted the Modification Applications.[37] In particular, the Modification Applications seek to cement into Ligado's licenses the substantial power and OOBE reductions requested by the GPS companies, agreed to by Ligado and specified in the Co-Existence Agreements. The Modification Applications thus address the GPS industry's core concerns regarding the potential incompatibility of existing GPS receivers and Ligado's proposed operations — and demonstrate how interference issues can be solved by neighbors willing to engage in good-faith discussions about legitimate issues. The following chart illustrates the proposed changes to power level and OOBE limits that are contained in the Modification Applications:

[37] *See* Letter from Gerard J. Waldron, Counsel to New LightSquared LLC, to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 12-340 and 11-109; IBFS File Nos. SAT-MOD-20120928-00160, SAT-MOD-20120928-00161, and SES-MOD-20121001-00872, at 1 (filed Dec. 31, 2015) (Ligado Dec. 31, 2015 Ex Parte).

Technical Operating Parameters Specified in Coexistence Plans



Note: The Coexistence Plans also include narrowband limits not depicted here.

The Modification Applications first request that the Commission rescind Ligado's ability to use the 1545-1555 MHz band for terrestrial service. Second, the Modification Applications propose a much more restrictive set of operational parameters than currently authorized in the three other bands. Specifically, the Modification Applications propose reduced power levels on a nationwide level for base stations that would operate in the 1526-1536 MHz portion of the band and user equipment in the 1627.5-1637.5 MHz and 1646.5-1656.5 MHz portions of the band.[38] Finally, to further protect certified aviation GPS devices, the Modification Applications propose that Ligado's license be conditioned on power limitation requirements for operation in the 1526-1536 MHz band across the country 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 ("FAA").[39]

The RAA Testing

RAA's test data was submitted into the record for this proceeding on May 11, 2016. RAA's test data verifies that the operational parameters agreed to by Deere, Garmin, and Trimble in the Co-Existence Agreements, and embodied in the instant Modification Applications, protect GPS operations. As Ligado's May 11, 2016, filing explains in detail, RAA concludes that Ligado's utilization of the spectrum licensed to it for terrestrial use is compatible with existing GPS operations as implemented by leading device manufacturers. Furthermore, the RAA data confirms that the new parameters set forth in the Co-Existence Agreements (which were filed with the Commission[40]) do indeed ensure that consumers using GPS-equipped devices

[38] *See* Modification Applications, Description of Proposed Modification at 4-7 (setting forth the particular technical details of the proposal).

[39] *See* Modification Applications, Description of Proposed Modification at 10-12.

[40] *See supra* note 4.

such as smartphones and general navigation devices can be confident that their devices will not be adversely affected if Ligado uses its spectrum for terrestrial use consistent with the power limits requested in the Modification Applications. The RAA data further confirms that, for certain industrial uses, many GPS devices are designed in such a way that they can co-exist with Ligado's proposed network. Other devices will not be used near any network facility or can be retrofitted cost effectively well before Ligado's network would begin operation.[41]

The RAA study was designed to measure what, if any, effect Ligado's proposed terrestrial network operations would have on the ability of GPS devices in various market segments to accurately provide position measurements — that is, to accurately tell the users of the device where they are. Importantly, RAA's analysis focused on evaluating the results in the context of the power limits and OOBE limits proposed in the Modification Applications. The only parameters relevant to determining whether GPS devices will experience actual harm under Ligado's proposed deployment are the power and OOBE limits set forth in the Modification Applications, since those are the limits under which Ligado proposes to operate. Unlike RAA's analysis, the 2012 testing referenced above used power and OOBE limits that are now obsolete and also entailed testing in bands in which Ligado no longer proposes to operate. Furthermore, consistent with Ligado's continued call for transparency in any GPS compatibility testing, all of the results from the RAA testing are publicly available and not anonymized.

RAA ultimately selected for testing General Location and Navigation (GLN), cellular, and high prevision devices, as well as a non-certified aviation device. Careful consideration went into RAA's determination of which devices to select for testing. RAA reviewed the various categories that comprise the GPS receiver market. The largest of these categories — based on

[41] *See* Bazelon Report, *supra* note 9, at 30.

the number of devices installed in the market — is cellular handsets, followed by GLN devices.[42] High precision devices represent a much smaller segment of the GPS market, although high precision devices can be more vulnerable to interference since many of these devices have relatively wide RF front-end bandwidths as they have been designed to receive an MSS augmentation signal in the 1525-1559 MSS band.[43] The devices RAA selected are produced by leading manufacturers and are devices for which it was feasible for third-parties to access usable data from the devices. Nine of the devices RAA tested also overlap with the devices tested in the TWG testing process. These devices include the Garmin GPSMAP 696, Garmin aera 510, Garmin eTrex H, Motorola APX 7000, Motorola MW810, Deere Starfire 3000, Topcon SGR-1, Trimble Net R9, and NAVCOM SF-3050.[44] RAA also considered that manufacturers in the GPS consumer device industry (other than cellular handset manufacturers) largely share a common supply chain and use similar or identical GPS consumer device component parts.[45] Accordingly,

---

[42] Bazelon Report, *supra* note 9, at 26 fig. 6.

[43] These wide RF front-end receivers are no longer necessary since Ligado has committed to provide this augmentation signal in the 1555 MHz band and higher, which provides sufficient separation between any MSS augmentation and any terrestrial use of the L-band.

[44] Meaningful performance data could not be obtained from the Deere Starfire 3000 device, a high precision device intended for the agricultural market, because the augmentation signal which it requires was not able to be obtained in the location where the testing was conducted. However, the manufacturer already has determined that it does not object to Ligado's LTE deployment.

[45] u-blox is an example of a manufacturer whose GPS receiver components are used in wide variety of market segments. Lacking specific market share information on which end-user devices incorporated GPS receiver components from manufacturers like u-blox, RAA based its selection of receivers to test based on devices available to end-users, with the expectation that GPS component suppliers would be well represented in that population. Additionally, RAA's test methodology incorporated a u-blox 7 receiver as a standard reference receiver present in the test chamber during all the tests.

the RAA study is directly relevant since it focuses on devices from leading manufactures in the primary sectors of the GPS industry.[46]

RAA first tested a device's baseline ability to accurately measure its position in the absence of any LTE signals by comparing the device's reported position with the device's "true" position. RAA then compared the device's baseline performance with the device's performance in the presence of adjacent band LTE signals under the parameters Ligado has proposed in the Modification Applications.

RAA's testing found the following about the classes of GPS devices:

- **Consumer Devices**
    - **General Location and Navigation:** All 12 GLN devices tested — representing five manufacturers — maintained their baseline GPS position accuracy in the presence of Ligado's proposed operations under "Open Sky" conditions. Even when presented with GPS signals 16 times weaker than the levels a GPS receiver would experience outdoors with an unobstructed view of the sky, only one of these 12 devices showed any effect from LTE operations — an effect that appeared in only one of the four proposed LTE bands, only when the device was in motion (reflecting input received at a DOT Adjacent Band Study workshop), and at LTE power levels that will occur with extremely low probability. And the manufacturer of that device (Garmin) has stated that the parameters set forth in the Modification Applications "protects the interests of GPS users, and [Garmin] doesn't anticipate any performance-degradation issues for those using GPS-based technologies."[47]
    - **Smartphones and Tablets:** RAA tested three cellular devices (one tablet and two smartphones), which all maintained their baseline GPS position accuracy in the presence of Ligado's proposed operations. In fact, comparing the performance of the Samsung Galaxy S6 with its predecessor, the S5, shows that these cellular GPS devices' performance, which already is highly robust, continues to improve over time. This is consistent with the fact that cellular devices include multiple transmitters and receivers (cellular in multiple bands,

[46] Bazelon Report, *supra* note 9, at 29 tbl. 3.

[47] "New LightSquared Settles GPS Lawsuit with Garmin" Wall Street Journal, Dec. 17, 2016.

Bluetooth, Wi-Fi, etc.) collocated with the GPS receiver, which necessitates a design tolerant of other signals.[48]

- **Industrial Devices (High Precision):** RAA completed testing on a total of 11 devices, produced by four manufacturers.[49] This testing reviewed the 3D performance of high precision devices (as opposed to 2D), reflecting input that RAA received at a DOT Adjacent Band Study Workshop.

    - Two manufacturers offer devices that, in stock condition, maintain their baseline GPS position accuracy in the presence of Ligado's proposed operations. Four of the 11 tested devices are in this category, including one device (the NAVCOM SF-3050) that was tested by TWG.

    - One of these manufacturers also offers devices that, although they show an impact from Ligado's proposed operations in stock condition, showed no such impact when the device's stock antenna was replaced with a filtered antenna. Three devices are in this category.

    - One manufacturer's device, NovAtel's SMART6-L, is marketed as being "ideal for manual guidance and auto-steer agriculture applications,"[50] a use case in which the device would be unlikely to experience the received LTE power levels in a real world environment at which the device showed a performance impact in the test environment.

---

[48] *See* February 11 Ex Parte, *supra* note 29, Declaration of Bill Alberth at 2-3 ¶ 7.

[49] Due to technical issues, RAA was unable to obtain useable data from one additional device, the Deere Starfire 3000, *see supra* note 44. In any case, however, Deere does not object to Ligado's proposed operations, subject to the changes set forth in the Modification Applications.

[50] *See* "New SMART6-L™ Integrated GNSS Antenna from NovAtel Provides Ultra-Smooth Positioning and Exceptional Pass-to-Pass Accuracy," NovAtel (March 18, 2013), *available at* http://www.novatel.com/about-us/news-releases/news-releases-2013/new-smart6-l/ (last visited May 19, 2016) ("Jason Hamilton, Director of Marketing at NovAtel stated, 'The SMART6-L is ideal for manual guidance and auto-steer agriculture applications that benefit from ultra-smooth positioning and high pass-to-pass accuracy.'"); *see also* "NovAtel Releases SMART6-L Integrated GNSS High-Accuracy Antenna," GPS World (March 19, 2013), *available at* http://gpsworld.com/novatel-releases-smart6-l-integrated-gnss-high-accuracy-antenna/ (last visited May 19, 2016) ("The SMART6-L is designed for manual guidance and auto-steer agriculture applications that benefit from ultra-smooth positioning and high pass-to-pass accuracy."). Thus, its publicly available marketing claims support the statements included in the May 11, 2016 filing and commented on in NovAtel's May 19, 2016 filing. *See* Letter from Timothy St. J. Ellam, Counsel to NovAtel Inc., to Marlene H. Dortch, Secretary, FCC, IB Docket No. 11-109 *et al.* (filed May 19, 2016). Also, contrary to the suggestion in the May 19, 2016 letter, Ligado did reach out to NovAtel to discuss the RAA testing; Ligado CEO Doug Smith communicated on more than one occasion with NovAtel's CEO, both before and after the RAA submission.

- The remaining manufacturer offers devices that show an impact from Ligado's proposed operations only in the 1526-1536 MHz band. Three devices are in this category. However, RAA's analysis did not consider the effect of any additional power limits to which Ligado may be subject in connection with its request that the FCC condition Ligado's licenses on power limitation requirements for that band necessary to achieve compatibility with current and future Minimum Operational Performance Standards ("MOPS") that are incorporated into an active Technical Standard Order from the FAA. It is reasonable to expect that the operational power limitation restrictions necessary to satisfy the FAA requirements will resolve any issues with these devices operating in the 1526-1536 MHz band.

- **Non-Certified Aviation Device:** This device maintained its baseline GPS position accuracy in the presence of Ligado's proposed operations.

In sum, the RAA data shows that Ligado's license modification proposal, which was developed in consultation and reflect the parameters agreed upon with the three leading GPS device manufacturers, is compatible with devices in the largest GPS market segments. These revised operating parameters will enable Ligado to operate a terrestrial network in a manner compatible with existing GPS operations as implemented by leading device manufactures. The results also show that even in segments with more demanding requirements, leading GPS device manufacturers already are able to produce devices that coexist with Ligado's proposed operations. This result is possible because Ligado was willing to make significant changes in its operational parameters. The difference between Ligado's old operating parameters and its new proposed operating parameters is like the difference between a stadium floodlight and a night light. Yet for the sake of sake of putting this spectrum to its most productive use while also protecting GPS, Ligado urges the Commission to implement these revised operating parameters into Ligado's licenses.

2. *Measuring Key Performance Indicators is the Appropriate Method to Determine Whether Ligado's Proposed Operations Would Cause Harmful Interference.*

The testing that RAA undertook, examining Key Performance Indicators ("KPIs") such as position error, is the appropriate method to assess whether a proposed power and OOBE level would pose actual harm to GPS devices. Ascertaining positional error is consistent with Commission rules, sound engineering, and GPS manufacturers' own promises to their consumers.

Measuring position error is consistent with the Commission's rules. The Commission defines "harmful interference" as follows:

> Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the International Telecommunication Union] Radio Regulations.[51]

This definition of harmful interference, which comes from the constitution of the International Telecommunication Union's Radio Regulations, has been used by the Commission for decades.[52] Moreover, the Commission has made clear, in the Public Notice in this proceeding and elsewhere, that mere speculative claims of a *potential* interference risk, absent evidence of actual harm, are insufficient to justify imposing increased restrictions on other spectrum users.[53] It is axiomatic that for evidence to be given due weight by an expert agency it

---

[51] 47 C.F.R. § 2.1(c).

[52] *See* ITU Radio Regulations § 1.169; FED. COMMC'NS COMM'N, REPORT OF THE INTERFERENCE PROTECTION WORKING GROUP SPECTRUM POLICY TASK FORCE 8 (2002), *available at* http://transition.fcc.gov/sptf/files/IPWGFinalReport.pdf.

[53] *See Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, Order on Recon. and 2nd R&O, GN Docket No. 12-354, at ¶ 105 (May 2, 2016) ("In effect, requiring devices to be tested using a peak detector at max hold requires devices to be certified at their 'worst case' configuration which would present an unrealistic view (continued…)

needs to be consistent with that agency's rules. Thus, for a test of GPS devices to be given full consideration by the Commission as to whether it accurately measures harm to a GPS device, it should measure what the Commission has defined as harmful interference. Measuring device position error is therefore entirely consistent with the FCC rules.

Measuring position error also is consistent with how GPS manufacturers speak to their customers. GPS companies do not warrant their devices' C/N_0 performance to customers. Instead, they focus on the exact same metric of harm that RAA tested: position accuracy.[54] In fact, a review of the warranties of each of the 27 representative devices that Roberson and Associates tested shows that every device that warranties GPS accuracy does so in terms of position accuracy. None of the devices does so in terms of a change in C/N_0.[55] Determining the effect of terrestrial operations in adjacent bands on the accuracy warranted by GPS manufacturers in representations such as those cited above is therefore the appropriate analytical tool in assessing the ultimate impact, if any, to end users of the manufacturers' device.

---

of the actual interference potential of any given device. This approach is inconsistent with our oft stated rejection of worst case approaches to measurements and interference protection analysis."); *Amendment of the Commission's Rules with Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands*, Report and Order, GN Docket No. 13-185, ¶ 62 (Mar. 31, 2014) ("GPSIA's arguments that the proposed OOBE limit *may* present some risk of interference do not warrant deferring action on the proposed OOBE limit.") (emphasis in original). *See also* Public Notice at 8.

[54] *See* Comments of LightSquared to Department of Transportation, IB Docket Nos. 12-340 and 11-109; IBFS File Nos. SAT-MOD-20120928-00160, SAT-MOD-20120928-00161, and SES-MOD-20121001-00872 at 7-8 (filed Oct. 26, 2015).

[55] *See* Garmin GPSMAP 695/696 Product Brochure; Garmin GPSMAP 76 CSx Owner's Manual; Garmin eTrex Owner's Manual; Motorola APX 7000 Product Brochure; Motorola MW810 Product Brochure; Navcom SF-3050 Product Brochure; Topcon SGR-1 Product Brochure; Topcon System 310 Product Brochure; Trimble Geo 7x Product Brochure; Trimble R8 Product Brochure; Trimble R9 Product Brochure; Trimble SPS985 Product Brochure; Trimble SPS855 Product Brochure; Trimble TM3000 Product Brochure; Furuno GP32 Product Brochure; Garmin 78sc Product Brochure; Garmin Montana 650t Product Brochure; Topcon HiPer V Product Brochure.

Examining KPIs to ascertain position error measures harmful interference as defined by the FCC's rules using the same metric GPS manufacturers use when addressing their consumers. Therefore, examining KPIs is the appropriate metric to assess potential harmful interference.

The 1 dB C/N_0 standard is technically flawed in these circumstances for two reasons. *First*, GPS devices in the ordinary course of their operation experience changes in the received GPS signal power and/or noise floor of significantly greater than 1 dB in C/N_0 and yet still function smoothly.[56] These changes in C/N_0 may be caused by any number of sources, including foliage and urban canyons as well as ionospheric scintillation. In light of the many everyday occurrences that can impact C/N_0 values, GPS devices are designed to operate over large ranges of values. This reflects sound and smart engineering by the GPS device manufacturers: the devices are programmed to auto tune to ensure that tracking errors are relatively unchanged over large ranges of C/N_0. This feature is a strength of GPS devices and enables them to perform for consumers amidst the vagaries inherent in the natural world. Depending on user dynamics and embedded oscillator stability, even significant changes in the C/N_0 may not impact the device's position, velocity, and time outputs.[57] *Second*, GPS devices experience errors due to the inherent limitations of the natural world, including environmental and atmospheric conditions on any particular day, multipath fading, and the delay in the signal's path from satellite to receiver caused by changes in the troposphere.

---

[56] This phenomenon is evident throughout the RAA data, *see* Roberson Results Report *supra* note 6, but is particularly obvious in the slide in Appendix C at 26 (Trimble R8, Live Sky, GPS Only [No LTE Signal]).

[57] *See*, *e.g.*, Roberson Results Report, *supra* note 6, App'x A at 36 (Garmin eTrex, Open Sky with Motion, 1627.5-1637.5 MHz LTE [Uplink]); App'x C at 15 (Trimble R9, Live Sky, 1627.5-1637.5 MHz LTE [Uplink]); App'x D at 8 (Trimble AgGPS 542 [Zephyr Antenna], Open Sky, 1526-1536 MHz LTE (Downlink); App'x D at 56 (Trimble SPS985, Open Sky, 1627-1637.5 MHz LTE [Uplink]).

Due to these technical flaws, RAA's data shows that 1 dB was an unreliable predictor of harm in this context.[58]

Given this analysis, the Commission should assess the proposed Modification Applications and impact on GPS devices by examining position error as reported by the KPIs.[59]

C. The Proposed Power and OOBE Limits Will Address GPS Concerns.

Granting the Modification Applications will lock into place the substantially reduced power and OOBE limits that were agreed to by the GPS companies and will assure that GPS operations will not be harmed. This assurance will inure to the benefit of not only the three major GPS device manufacturers who took the lead with Ligado in developing a co-existence plan, but also to the benefit of the rest of the GPS industry and their consumers. Moreover, resolving the existing regulatory uncertainty in a way that protects GPS device manufacturers and consumers will encourage investment and increase the expected returns on investment in the GPS industry as a whole.[60]

The protections that would be guaranteed to the GPS industry by the Modification Applications are substantial and further underscored by the fact that GPS devices are continuing to improve, making the possibility of *any* impact on GPS at the time of Ligado's eventual deployment even more remote. For example, RAA observed in their testing that the Samsung S6 demonstrated improved GPS performance at low GPS signal levels when compared with the

---

[58] *Id.* at 13.

[59] For the reasons stated above, it would be arbitrary and capricious for the Commission to use a standard other than actual harm in assessing the instant Modification Applications, since that standard is embedded in the Commission's rules. *See FCC v. Fox Television Stations, Inc.*, 556 U.S. 502, 515 (2009).

[60] Bazelon Report, *supra* note 9, at 21-22.

earlier S5 model.[61] This reality of device improvement over time is also reflected in the agreement with Garmin, which contemplates certain additional power and OOBE limits that are time-limited and automatically sunset after five years.[62] Furthermore, because of the supply chain structure in the GPS consumer device manufacturing industry, improvements in Garmin and other leading consumer manufacturers' antennas, receivers, and other components will have a "ripple effect" that will permeate the industry.[63] Newly manufactured GPS devices would therefore also experience no impact from Ligado's plan.

Those newly manufactured GPS devices will constitute a significant and ever-increasing share of the devices in use at the time of Ligado's deployment. The product lifecycle for GPS devices — in which old devices are retired and new devices are purchased — shows that with respect to high-precision agriculture devices, less than half of today's installed base will still be in use in 2020.[64] Other categories of industrial-use GPS devices have a similar lifecycle.[65] Accordingly, RAA's testing not only employed conditions that simulated the worst of the worst scenarios, but also tested devices that no longer represent the state of the art and are in the normal course of being replaced in the marketplace as part of the typical GPS product lifecycle. The combination of the Modification Applications' reduced power and OOBE limits and

---

[61] Roberson and Associates, LLC, *GPS and Adjacent Band Co-Existence Study: Summary of Method and Results*, IB Docket No. 11-109, at 28–30 (filed May 11, 2016) (hereinafter, "Roberson Summary of Method and Results").

[62] *See* December 17 Ex Parte, *supra* note 4, Settlement Agreement and Releases at 17 & Exhibit C.

[63] *See* February 11 Ex Parte, *supra* note 29, Declaration of Bill Alberth at 2 ¶ 6; Bazelon Report, *supra* note 9, at 31.

[64] Bazelon Report, *supra* note 9, at 33 fig. 7.

[65] *Id.*

improved GPS devices ensures that the interests of GPS manufacturers and consumers will be fully protected.

IV. THE PROPOSED CONDITION ON THE LOWER DOWNLINK BAND PROMOTES SAFETY AND RESULTS IN ONGOING COMPLIANCE WITH FAA'S SAFETY REQUIREMENTS

Ligado is committed to addressing the aerospace industry's flight testing requirements, as demonstrated most recently by Ligado's coordination agreement with the Aerospace and Flight Test Radio Coordinating Council with respect to protections for aeronautical mobile telemetry.[66] Ligado's proposed terrestrial mobile network also will be fully compatible with the aviation sector's use of GPS. The Modification Applications propose to ensure this compatibility in three ways.

First, Ligado has requested that the Commission remove Ligado's authority to conduct terrestrial operations in its upper 10 MHz downlink band at 1545-1555 MHz — the part of Ligado's downlink band that is closest to the GPS band — while proposing to modify the equivalent isotropically radiated power ("EIRP") limit for Ligado's lower 10 MHz downlink band at 1526-1536 MHz from 42 dBW to 32 dBW.[67] Notably, these changes are consistent with one of the key mitigation measures suggested in the TWG Report for the protection of aviation-related GPS operations.[68]

Second, Ligado's revised operating parameters, which will apply on a nationwide basis (and *not* just around airports), ensure greater protection to all GPS devices, including those used by pilots, aircraft operators and airports that are not certified aviation devices. These devices

[66] Letter from Dan Robinson, President, AFTRCC, and Jeffrey Carlisle, Executive Vice President for Regulatory Affairs, Ligado Networks LLC, to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 11-109 & 12-340 (filed May 23, 2016).

[67] *See* Modification Applications, Description of Proposed Modification at 6.

[68] *See* TWG Report at 3.1.11.1.

include those that are used primarily by the general aviation community for "situational awareness." They are not approved for primary navigation but may be used by a pilot as a supplement to approved primary sources of navigational information. They may also be used by ground-based support vehicles operated by airlines and airports on and near airport property. RAA's testing demonstrates that devices in this category are compatible with Ligado's proposed terrestrial operations.

Third, in addition to the proposed EIRP limits, Ligado would limit the power of its terrestrial network operations in the 1526-1536 MHz band on a nationwide basis as necessary in deference to current and any future MOPS insofar as they are incorporated into active Technical Standard Orders ("TSOs") by the FAA and the industry-led Radio Technical Commission for Aeronautics ("RTCA").[69] The Modification Applications request that the Commission make adherence to these standards a condition of Ligado's licenses.[70]

This ongoing coordination process will determine the maximum Ligado EIRP that is compatible with certified aviation GPS standards, as embodied in the relevant MOPS and TSOs. Much of the work required to make this determination already has been accomplished through the previous work undertaken by RTCA in 2014 and 2015. During this period of time, RTCA provided the FAA with significant input on the analysis which would be necessary in order to

[69] As the RTCA's website states, "RTCA works in response to requests from the Federal Aviation Administration (FAA) to develop comprehensive, industry-vetted and endorsed recommendations for the Federal government on issues ranging from technical performance standards to operational concepts for air transportation. Our deliberations are open to the public and our products are developed by aviation community volunteers functioning in a consensus-based, collaborative, peer-reviewed environment." "About Us," RTCA, http://www.rtca.org/content.asp?pl=49&contentid=49 (last visited May 23, 2016).

[70] Modification Applications, Description of Proposed Modification at 7.

determine compatibility with operation of certified aviation devices.[71] The parameters in which RTCA input was provided included the following:

- Appropriateness of receiver susceptibility and antenna models proposed by the FAA
- Identification of propagation models for various distances from Ligado transmitters
- Levels for background environmental noise contributed by other wireless emitters

This input was in addition to key assumptions that are outlined in existing RTCA MOPS such as DO229-D which include:

- Defined performance of GPS receive antenna
- Assumed GPS signal strength
- Maximum tolerable adjacent band power at GPS antenna

Resolution of remaining questions, such as the appropriate standoff distance from a Ligado transmitting antenna by which to assess the Ligado power for the purposes of the compatibility assessment, and the protection distances required around low-altitude approach and departure routes from airports and heliports (*i.e.* zones in which the placement of Ligado transmitters would be restricted) would be accomplished through additional coordination with the FAA based on the input it has already received from aviation stakeholders through RTCA. We also expect FAA to review its analysis with RTCA to ensure that the entire aviation community is consulted on these power levels.

[71] *See* RTCA Tactical Operations Committee, "GPS Adjacent Band Compatibility: Feedback on Exclusion Zones," http://www.rtca.org/files/Final%20TOC%20GPS%20ABC.pdf (July 2015); RTCA Special Committee 159, "Summary of the Ninety-third Meeting," RTCA Paper No. 076-15/SC159-1037, http://www.rtca.org/Files/Committee%20Meeting%20Summaries/SC-159_Mar_2015_Summary.pdf, at 7 (Aug. 24, 2015) (reporting approval of Response to Questions 1-3 from FAA's GPS Adjacent Band Compatibility Study Methodology and Assumptions at SC-159's at March 20, 2015, meeting).

Once these issues are resolved, the maximum Ligado EIRP in the 1526-1536 MHz band compatible with the applicable MOPS and TSOs can be determined using straightforward calculations and automatically applied to Ligado's operations without further Commission action beyond imposing the license conditions requested in the Modification Applications. This deferential regulatory model is consistent with the Commission's approach in other contexts where the Commission has found it appropriate to incorporate the specialized expertise of another agency or standards body into the Commission's own requirements.[72]

By conditioning Ligado's operations on compliance with applicable MOPS incorporated in FAA TSOs, the Commission would benefit from the FAA's specialized expertise and authority in ensuring the safety of critical aviation operations. At the same time, the Commission would retain its independent role in regulating Ligado's use of spectrum, including the Commission's authority to enforce Ligado's compliance with its license conditions through

[72] *See, e.g.*, *Amendment of Parts 13 and 80 of the Commission's Rules Concerning Maritime Communications*, 2nd R&O, 6th R&O, and 2nd FNPRM, 19 FCC Rcd 3120, 3137 (2004) (authorizing use of INMARSAT-E emergency position indicating radiobeacons, subject to compliance with International Electro-technical Commission standard 61097-5); *Reassessment of Federal Communications Commission Radiofrequency Exposure Limits And Policies*, 1st R&O, FNPRM and NOI, 28 FCC Rcd 3498, 3515 (2013) (noting that classification of the outer ear as an extremity for purposes of human RF exposure guidelines is "supported by the expert determinations of the FDA and of the IEEE," and that "[t]he FDA in particular has statutory responsibility to carry out a program designed to protect public health and safety from electronic product radiation and we therefore place heavy reliance on its public health and safety determinations"); *Applications of Cellco Partnership d/b/a Verizon Wireless and SpectrumCo LLC and Cox TMI, LLC for Consent to Assign AWS-1 Licenses*, 27 FCC Rcd 10698, 10766 (2012) (conditioning foreign ownership authorization on licensee's continued compliance with agreement reached with U.S. Department of Defense, U.S. Department of Justice, FBI, and U.S. Department of Homeland Security); 47 C.F.R. § 64.1200(a)(2), (a)(3)(v) (exempting from certain telemarketing requirements calls governed by specified provisions of the HIPAA Privacy Rule promulgated by the U.S. Department of Health and Human Services).

the Enforcement Bureau's ordinary processes.[73] Ad hoc interference concerns could be addressed either by FAA field compliance personnel or the Commission's Enforcement Bureau, both of which are well-equipped to handle such complaints. This regulatory partnership between the Commission and the FAA thus would serve the public interest by allowing Ligado to put its spectrum to productive use while ensuring that Ligado's operations are at all times compatible with the needs of the nation's aviation sector.

CONCLUSION

For the reasons set forth herein, the above-captioned Modification Applications should be granted.

Respectfully submitted,

/s/Gerard J. Waldron

Gerard J. Waldron
Michael Beder
Dustin Cho
Ani Gevorkian
COVINGTON & BURLING LLP
One CityCenter
850 Tenth Street, NW
Washington, DC 20001
(202) 662-6000

Counsel for Ligado Networks LLC

Attachments

May 23, 2016

[73] *See* 47 C.F.R. § 0.111(a)(4) (delegating to the Enforcement Bureau the authority to "[r]esolve complaints regarding radiofrequency interference and complaints regarding radiofrequency equipment and devices").

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Comment Sought on Ligado's Modification Applications	)	IB Docket No. 11-109
	)	

DECLARATION OF SCOTT WIENER

1. My name is Scott Wiener. I am currently the Chief Marketing & Strategy Officer at Ligado Networks, LLC ("Ligado"), a position I have held since February 1, 2016. Previously, I served as an advisor to the company (then called LightSquared) from the spring of 2012 to January 31, 2016 in my capacity as co-founder and partner of the consultancy Alta Nova Group. Prior to founding Alta Nova Group, I was Senior Vice President of Strategy & Planning at LightSquared from the fall 2010 to the spring 2012, where I was in charge of the company's strategic planning, market research, and business analysis.

2. I have approximately 25 years of telecommunications and technology experience in strategy, business planning, pricing management, marketing, and business development. Prior to my roles at Ligado Networks, Alta Nova Group, and LightSquared, I served as a strategy and marketing advisor to early-stage technology ventures, service providers, and institutional investors. I previously held executive marketing and strategy roles at Nextel Communications and Sprint and began my career as a market development manager at MCI. I received a B.A. in American History from Brandeis University and an M.B.A. from New York University's Stern School of Business.

3. In June 2015, Roberson and Associates ("RAA") was engaged to advise on spectrum interference issues and conduct tests on how deployment of LTE at various power levels would affect the performance of GPS devices. RAA was hired for a number of reasons, including to enable the company to be highly-informed when the company discussed spectrum and network deployment issues with GPS device manufacturers and the Department of Transportation ("DOT"). This was my first time working with RAA, but I knew generally about their considerable experience in analyzing shared spectrum, both for private companies and in Federal Communications Commission ("FCC") working groups. LightSquared also wanted to be more knowledgeable about what was important to major GPS device manufacturers, so the company could propose ways to resolve concerns about interference and cooperate with them.

4. LightSquared began receiving preliminary data from RAA on October 16, 2015, although the testing continued throughout the fall, and the company consistently received supplemental data. The results largely confirmed our understanding from the 2012 multi-stakeholder testing process we participated in along with other GPS industry members and the National Telecommunications and Information Administration ("NTIA"). For example, given the 2012 testing we were un-surprised by the issues that the RAA data identified in some devices operating in our lower downlink. As we had intended, the RAA data provided us with examples of how different devices would function in different conditions.

5. I regularly briefed Doug Smith, the company's President and CEO, on the incoming RAA results throughout the fall of 2015. With this information, the company was able to evaluate various technical operating parameters and review operational and business considerations associated with substantially reduced power and OOBE levels in various bands of our spectrum to ensure that we could coexist with our spectrum neighbors.

6. As intended, the preliminary RAA test results also informed our discussions with Deere, Trimble, and Garmin, the three GPS device manufacturers with whom we were working to resolve various spectrum and business matters. The RAA data gave us a better sense of the specific concerns of the GPS companies with our uplink and downlink bands. It also enabled us to discuss limitations that would ensure our ability to coexist with the GPS devices, since we understood what the GPS device manufacturers needed in terms of planning and ensuring their devices could co-exist with the company's deployment of LTE.

7. I am focused on marketing and strategy for the company. Others at the company make assessments on engineering and spectrum, but I consider those engineering inputs in terms of how they may affect potential business opportunities. In this regard, the RAA data served as an input for evaluating concessions that the company would need to make in order to resolve its spectrum discussions and negotiations with the GPS device manufacturers. The technical operational parameters negotiated by the company and the GPS device manufacturers, in turn, permitted the company to prepare for its emergence from bankruptcy and determine network deployment parameters that would enable LTE and GPS devices to co-exist.

Signed: Scott Wiener

Date: May 23, 2016

Putting Mid-Band Spectrum to Work:

Sharing between Ligado Networks and its GPS Neighbors

PREPARED FOR

FCC

PREPARED BY

Coleman Bazelon

May 23, 2016

THE Brattle GROUP

This report was prepared for FCC at the request of Covington & Burling LLP. All results and any errors are the responsibility of the authors and do not represent the opinion of The Brattle Group or its clients.

Acknowledgement: I acknowledge the valuable contributions of many individuals to this report and to the underlying analysis, including Christine Polek, James Wieler, Dan Luo, Haris Tabakovic, Shamael Mahmood, and other members of The Brattle Group for peer review.

Copyright © 2016 The Brattle Group, Inc.

Table of Contents

I. Executive Summary 1

II. Assignment 5

III. Benefits from Ligado's Spectrum 6

- A. Value Created by Proposed License Modifications Is Large 6
- B. Unique Opportunity For Mid-Band Spectrum 10
  - 1. The 5G Future 10
  - 2. Productive Use of Ligado's Terrestrial Spectrum 14
  - 3. The FCC's Policy Choice 15

IV. The Proposed License Modifications Minimize Harm and Allows GPS and Ligado to Co-Exist 18

- A. The Modification Applications 18
- B. No Evidence of Cost to the Majority of the GPS Industry 22
  - 1. GPS Usage 22
  - 2. Evidence of Only Minor Costs to GPS Industry 26
  - 3. RAA Testing Results 27
- C. Plan Costs are Borne by Ligado 34

Appendix 1. The Market for Commercial GPS Devices A-1

- A. Installed Base, Sales, and Retirements A-1
- B. Market Shares A-5

Appendix 2. The Settlements with Leading Industry Manufacturers A-7

I. Executive Summary

Through its spectrum policies, the Federal Communications Commission has created the foundation for the U.S.'s leadership in mobile wireless over the past decades. The Commission understands the need for additional spectrum to continue this leadership, and has worked hard to fulfill the President's goal of an additional 500 MHz for mobile broadband in this decade. Future deployments of wireless networks will be focused on implementation of the next generation of wireless technologies and architectures known as 5G. Key to effective 5G deployments will be more unencumbered, greenfield spectrum.

As demand for wireless services grows—driven by individuals' desires to always be connected and now our desire to also connect all of the things in our lives—it becomes increasingly critical that we use our scarce spectrum resources as efficiently or smartly as possible. The 5G future promises that. It represents the culmination of research and experience in operating wireless networks. For example, it will use the latest network technologies, such as taking advantage of radio signals' ability to take multiple paths from transmitter to receiver to create bandwidth multipliers. Also key to this future is to be mindful of the relative advantages of different frequency bands. Higher, and more abundant, frequencies are best for shorter distances. These are also likely to create the largest demand for capacity. Mid-band spectrum is best deployed for mid-range communications and the lower frequencies (under 1 GHz) reserved for the longest range communications. Over the long run, wireless networks cannot afford to mismatch the type of communications with frequencies they are transmitted over because the networks will not be able to tolerate the inefficiencies created.[1]

Ligado's[2] commitment to the deployment of its terrestrial mid-band spectrum is a greenfield opportunity that is perfectly aligned with the FCC's stated goals of providing the foundation of the 5G future. [3] FCC Chairman Wheeler has repeatedly said that American leadership in 5G is a

---

[1] See, Smith, Doug, "Looking Forward to a 5G Future for the U.S. Wireless Industry," Ligado, (May 23, 2016), http://ligado.com/blog/.

[2] Ligado Networks LLC ("Ligado") was formerly New LightSquared and before that LightSquared. For purposes of this commentary, I refer to Ligado Networks LLC and its predecessor companies as "Ligado."

[3] "Ligado Networks is eager to be an integral part of this new wireless age…We are committed to data-driven problem solving to finally deploy this mid-band spectrum for terrestrial use, upon FCC

Continued on next page

national priority and that the U.S. would allocate spectrum for 5G "faster than any nation on the planet."[4] In fulfilling this future, network operators need more spectrum to deploy the latest networks. Doing so requires greenfield spectrum—frequencies unencumbered by existing networks. Unlike refarming mobile broadband spectrum, say when a 3G band is upgraded to 4G, where bands can be converted piecemeal, the networks needed for very high capacity or connecting objects in an Internet of Things (IoT) will require new sources of greenfield spectrum suitable for mobile coverage networks. Ligado's frequencies represent a prime greenfield opportunity to fill the mid-band needs of these future networks.

By adopting the modifications proposed in its Public Notice,[5] (herein the "Modification Applications"), the FCC will fulfill its own goals of facilitating the 5G future of wireless networks. Ligado's 40 MHz of mid-band greenfield spectrum is an important complementary asset that is desperately needed to facilitate America's growing wireless economy and extend American mobile leadership in 5G. Moreover, by implementing the Modification Applications, the FCC will enable significant economic activity and employment for thousands of people will be generated. And this can all be accomplished while protecting GPS users.

Two major GPS device manufacturers (Deere and Garmin) do not object to the modification of Ligado's licenses for terrestrial use at the significantly-reduced power levels in all of Ligado's

---

Continued from previous page

approval." Smith, Doug, "Looking Forward to a 5G Future for the U.S. Wireless Industry," Ligado, (May 23, 2016), http://ligado.com/blog/.

4 See, Remarks of FCC Chairman Tom Wheeler INCOMPAS Policy Summit (April 11, 2016), p.1 accessed May 19, 2016, https://apps.fcc.gov/edocs_public/attachmatch/DOC-338806A1.pdf; Alleven, Monica, FierceWirelessTech, "Wheeler: U.S. will allocate 5G spectrum 'faster than any nation on the planet'" (March 2, 2016), accessed May 19, 2016, http://www.fiercewireless.com/tech/story/wheeler-us-will-allocate-5g-spectrum-faster-any-nation-planet/2016-03-02.

5 Letter from Gerard J. Waldron to Marlene H. Dortch, IB Docket No. 12-340 and IB Docket No. 11-109 (December 31, 2015), accessed February 4, 2016, http://apps.fcc.gov/ecfs/document/view?id=60001396805. *Comment Sought on Ligado's Modification Applications,* April 22, 2016, IB Docket Nos. 11-109 and 12-340, Public Notice (DA 16-442) *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*, April 22, 2016, RM-11681, Public Notice, DA-16-443. This paper is responsive to the FCC's request for comments on Ligado's Modification Applications.

bands. Trimble, another major GPS device manufacturer, supports Ligado's license modifications in all bands except one, the lower downlink. In accordance with the agreements reached between Ligado and three of the major GPS device manufacturers, Ligado is fulfilling its obligations under the agreements to have these power and out of band emission restrictions codified into its FCC licenses.[6]

Codifying these technical parameters benefits the GPS industry by guaranteeing that, no matter who owns or operates the licenses, these conditions must be honored. In addition, the conditions could be submitted by Ligado to the 3GPP standard setting process, which could encourage other nations similarly to adopt these restricted power levels for terrestrial use of these bands, and thus the GPS firms would be able to design and market globally with knowledge that these limits are worldwide. Finally, although private parties may agree to spectrum power limits, only the government can set them. Therefore, these parties wish to convince the FCC and other affected agencies that their agreement is in the public interest. My conclusion is that this is the case and that the FCC should set the referenced power limits.

My conclusions are based on three principal findings. First, in the consumer category, which represents the vast majority of the GPS market, there is no evidence that GPS users and manufacturers will incur additional costs because there is no evidence of degradation of the user's experience or any decrease in manufacturer's profits from adjacent band terrestrial operations. In the industrial category, there is a subset of devices that experience interference at certain power levels. Compatibility of these devices is easily addressed through some combination of reduced power limits – specific to Ligado's lower downlink operations, which are subject to satisfying FAA requirements – or new device components that would come at an acceptable cost.

Second, the costs to implement these spectrum license modifications are borne entirely by Ligado. Most significantly, the company has proposed to relinquish terrestrial authorizations to half of their terrestrial down-link spectrum—a 10 MHz band nearest the GPS users. They have also agreed to a number of technical restrictions that reduce the power at which they can operate on their remaining frequencies, including the restriction that its lower downlink operations

---

[6] "We reached the agreements by asking the device makers what they needed." Smith, Doug, "Looking Forward to a 5G Future for the U.S. Wireless Industry," Ligado, (May 23, 2016), http://ligado.com/blog/.

satisfy FAA requirements. Furthermore, the 5 MHz of NOAA spectrum they seek to have auctioned by the FCC for shared use has protection zones for NOAA satellite receive stations.

Third, the license modifications enable putting Ligado's spectrum to beneficial use. This will provide desperately needed new greenfield mid-band spectrum for the emerging 5G wireless industry.

The public interest is served when policies create value and benefit society. That is the case here and can be seen by comparing the benefits and costs of the proposed license modifications. With large benefits to the U.S. economy and consumers, no costs to the vast majority of GPS users and only modest potential costs to remedy a narrow subset of industrial devices, and the costs in deploying its network and enabling productive use its spectrum borne solely by Ligado, the benefits clearly outweigh the costs.

II. Assignment

I am an economist with extensive experience in analyzing telecommunications markets generally and wireless market specifically. From 1995 to 2001, I was an Analyst at the Congressional Budget Office evaluating radio spectrum reform proposals and estimating FCC spectrum auction receipts. Since 2001, I have been in private practice continuing to focus on telecommunications economics and policy. I have testified at the FCC and before the U.S. Congress on wireless policy matters and filed numerous analyses at the FCC. I have also consulted for most national entities in the telecommunications sector as an expert witness in litigations, analyzing policy proposals, and in providing strategic advice. My CV is attached.

I have been asked by Covington & Burling LLP to evaluate if the economic implications of the Modification Applications are in the Public Interest. Specifically, I was asked to address the value created by putting mid-band spectrum into service for terrestrial mobile networks, any economic costs to GPS users and manufacturers, and burdens borne by Ligado. I am an economist, not an engineer or lawyer. Consequently, I rely on the engineering analysis by Roberson and Associates ("RAA") to evaluate any physical interference issues and leave to lawyers to address legal standards for harm, and I instead focus on economic benefits and costs, to both specific economic actors and to society at large. In evaluating these costs and benefits, I find that the societal benefits from the Modification Applications clearly outweigh any associated costs.

III. Benefits from Ligado's Spectrum

A. Value Created by Proposed License Modifications Is Large

Wireless broadband service is currently the highest valued commercial use of spectrum – both in terms of economic value and social welfare. Ligado and its predecessors have invested over $4 billion in an effort to put its spectrum to efficient use,[7] and are prepared to invest over one billion more in order to repurpose frequencies near the GPS band for a terrestrial mobile network.[8]

Ligado's holdings are mid-band spectrum, specifically 20 MHz of terrestrial downlink spectrum in the 1525-1559 MHz block, 20 MHz of terrestrial uplink spectrum in the 1626.5-1660.5 MHz block,[9] and leased rights to 5 MHz of downlink in the 1670-1675 MHz band held by Crown Castle International Corporation ("Crown Castle").[10] The allocation to RNSS that has been

---

[7] See Coleman Bazelon, "Implications of Regulatory Inefficiency For Innovative Wireless Investments", March 15, 2012, footnote 2, available in Comments in Opposition of LightSquared Inc., Exhibit 6, IB Docket No. 11-109, File No. SAT-MOD-20101118-00239, http://apps.fcc.gov/ecfs/document/view?id=7021901726.

[8] 2015. "New LightSquared, Same Agenda, Billions at Stake." GPS World 25, no. 8: 7-9. Business Source Corporate Plus, EBSCOhost (accessed May 20, 2016).

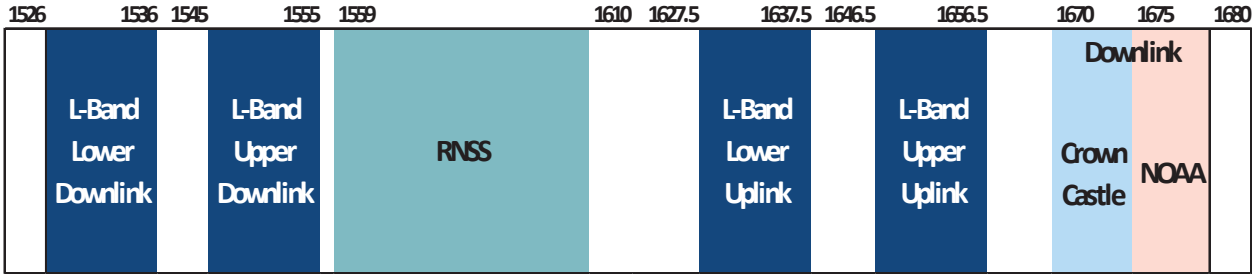
[9] For spectrum services that require two-way communications, such as mobile phone services, provision has been over paired bands of spectrum. With a paired band, a portion of the frequencies (traditionally half) are used to transmit from the base station to the mobile device (the "downlink", i.e., the frequency used to download data) and the remainder is used for mobile to base station transmissions ("uplink", i.e., the frequency used to upload data). Pairing bands diminishes interference from incompatible adjacent operations (See discussions on AWS-3 band interference in "Notice of Proposed Rulemaking in the Matter of Service Rules for Advanced Wireless Services in the 2155-2175 MHz Band." FCC Docket 07-164 adopted September 7, 2007, released September 19, 2007; and in "AWS-3 To AWS-1 Interference Laboratory Test Report." T-Mobile USA, Inc., To avoid interference, the FCC could set power restrictions on the single band, which would decrease its capacity, see, "Advanced Wireless Service Interference Tests Results and Analysis." FCC, October 10, 2008.

[10] OP LLC ("OP") is an indirect subsidiary of Crown Castle. In 2007, OP leased its spectrum rights, through a long-term de facto transfer spectrum leasing arrangement, to TVCC One Six Holdings LLC, a predecessor of LightSquared. The 1670 – 1675 MHz band terrestrial license was renewed by the FCC through October 2023. See, FCC, "Wireless Telecommunications Bureau Seeks Comment On Request

Continued on next page

assigned to the GPS satellite system is located between frequencies licensed to Ligado.[11] Figure 1 below illustrates the proximity of the L-Band downlink and L-Band uplink segments of the Ligado spectrum to GPS spectrum, and that the Crown Castle spectrum leased by Ligado is adjacent to NOAA spectrum.

Figure 1: Ligado's Spectrum



There is growing demand for spectrum, and that demand is becoming more pressing as the era of 5G arrives. Ligado's proposal to enable its licensed L-Band spectrum for terrestrial use helps alleviate demand for spectrum and creates additional capacity. The benefits associated with the deployment of Ligado's next-generation mobile network include serving critical user segments like public safety and homeland security, introducing differentiated network capabilities, and accelerating delivery of innovative applications for an array of end user devices.[12]

Continued from previous page

By Op LLC For Extension Or Waiver Of The Construction Deadline Concerning Its 1670-1675 MHz Band License", November 5, 2012, http://transition.fcc.gov/Daily_Releases/Daily_Business/2012/db1105/DA-12-1776A1.txt

[11] The 1559 MHz – 1610 MHz is a shared band internationally allocated to the radionavigation-satellite service (RNSS) in the space-to-earth and space-to-space directions. Global Navigation Satellite Systems (GNSS) is the standard generic term for radionavigation-satellite systems that provide autonomous geo-spatial positioning with global coverage. The GNSS allows receivers to determine their location (longitude, latitude, and altitude) using signals transmitted from satellites. The predominate use of the 1559-1610 MHz band is for the U.S. Global Positioning System (GPS) See, "1559-1610 MHz", NTIA, March 1, 2014, https://www.ntia.doc.gov/files/ntia/publications/compendium/1559.00-1610.00_01MAR14.pdf.

[12] See, Order and Authorization for LightSquared, File No. SAT-MOD-20101118-00239, p. 5, January 26, 2011.

Ligado's spectrum could contribute significant value by simply adding capacity to current networks, but also presents comparable opportunities that could leverage both their next-generation satellites and the greenfield nature of their spectrum to enable 5G applications that require ultra-reliable, highly-secure, enhanced precision, and pervasive connectivity. From an economist's perspective, spectrum should be put to its highest value use, which can be through 5G use cases of Ligado's spectrum. For example, any demand met by Ligado's spectrum for 5G applications will help relieve the demand on existing networks and other 5G deployments. Consequently, its spectrum should be valued in the context of being deployed as an asset in a 5G network.

In previous work, I estimated that the economic value of the 645.5 MHz of licensed mobile broadband spectrum is almost $500 billion.[13] In addition, for mobile wireless services, economists estimated that the total social benefits from licensed spectrum are at least 10 to 20 times the direct economic value of the spectrum, which amounts to the total social welfare of between $5 trillion and $10 trillion.[14] Moreover, every dollar spent on wireless service resulted in $2.32 of total spending, suggesting a significant multiplier effect in the sector.[15] Across all carriers, wireless services directly contributed about $200 billion to the U.S. GDP in 2013. The wireless industry also creates jobs. It is estimated that employing 1 person in the wireless industry results in an additional 6.5 people finding employment—again a significant multiplier effect.[16] Thus, there is significant direct and indirect economic effect of licensed spectrum.

---

[13] See, Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the American Economy", Prepared for CTIA – The Wireless Association, May 11, 2015, p.1, http://apps.fcc.gov/ecfs/document/view?id=60001117200.

[14] See, Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the American Economy", Prepared for CTIA – The Wireless Association, May 11, 2015, p.1, http://apps.fcc.gov/ecfs/document/view?id=60001117200.

[15] See, Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the American Economy", Prepared for CTIA – The Wireless Association, May 11, 2015, p.2, http://apps.fcc.gov/ecfs/document/view?id=60001117200.

[16] See, Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the American Economy", Prepared for CTIA – The Wireless Association, May 11, 2015, p.2, http://apps.fcc.gov/ecfs/document/view?id=60001117200.

Leveraging what is known about the value of wireless broadband more generally to indicate the economic benefits created by Ligado's L-Band spectrum and using conservative estimates of wireless broadband spectrum value of approximately $2.00 per MHz-Pop,[17] I estimate the value of 40 MHz of unencumbered spectrum to be $25 billion.[18] Ligado's spectrum is not unencumbered as they have agreed to numerous restrictions on its use that may increase the cost to deploy the spectrum.[19] Added costs from the encumbrances reduce the spectrum's commercial value.[20] But as a basis for estimating the social value of spectrum, the unencumbered value represents the benefits from deployments.[21] Such an asset value is only supported by significant annual revenue, on the order of $10 billion per year.[22] This value does not consider the immense social value wireless broadband spectrum generates. Economists estimate that the total social benefits from licensed spectrum are at least 10 to 20 times the direct economic value of the spectrum,[23] suggesting total social welfare of between $250 billion and $500 billion associated with 40 MHz of mid-band spectrum. In addition, as noted above, every dollar spent on wireless service results in spending of more than one dollar in the economy, and every job the wireless industry creates results in more people finding employment. Yet, all of these benefits have not even taken into consideration the potential benefit of 5G in the marketplace enabling the new

---

[17] Megahertz per population, the standard unit for measuring spectrum prices. $2/MHz-pop represents a 20% reduction from recently observed prices for other, AWS-3, mid-band spectrum. See, Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the American Economy", Prepared for CTIA – The Wireless Association, May 11, 2015, p.11, http://apps.fcc.gov/ecfs/document/view?id=60001117200.

[18] 40 MHz x $2/MHz-pop x 309.3 million (U.S. population as of 2010) / 1,000.

[19] As one example, lower power limits will reduce the maximum size of a cell site. This can require additional cell sites when the maximum size of the site matters.

[20] See, generally, Coleman Bazelon and Giulia McHenry, "Spectrum Value," Telecommunications Policy 37 (2013), pp. 737-747, for an explanation of how higher costs reduce the value of spectrum.

[21] At this time it is unclear the extent to which the license modifications would affect Ligado's use of the spectrum (and correspondingly the social and private value of the spectrum) because the network has not been developed.

[22] With margins of 25% and a discount rate of 10%, annual revenues of about $10 billion would be consistent with an asset value of $25 billion. ($10 billion * 25%)/10% = $25 billion.

[23] See, Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the American Economy", Prepared for CTIA – The Wireless Association, May 11, 2015, p.1, http://apps.fcc.gov/ecfs/document/view?id=60001117200.

types of commerce it will generate. There is no doubt that deploying Ligado's spectrum will generate tremendous economic and social value.

By contrast, annual revenue from the sale of all GPS devices, which rely on publically provided GPS signals, is $102 million—revenue that Verizon alone earns in less than a day.[24] In evaluating the public interest in the government approving the coexistence agreements reached by the GPS device manufacturers and Ligado, it is important to put the value created by terrestrial use of Ligado's frequencies into perspective. GPS adds significant value to the economy, as will deploying Ligado's mid-band spectrum. Fortunately, the license modifications proposed in the Public Notice will preserve the former and facilitate the latter.

B. Unique Opportunity For Mid-Band Spectrum

1. The 5G Future

Following in the footsteps of its predecessors, 3G and 4G technologies, and driven by bandwidth-hungry services like video streaming, 5G will provide large improvements in mobile broadband such as enhanced capacity, better reliability and higher data rates. The specific technology standards for 5G have not been set. Generally speaking, 5G is expected to have user throughput of up to 20 Gbps, edge latency of less than 1ms, system bandwidth of at least 100 MHz, simultaneous two-way communications in the form of frequency division duplex (FDD) and time division duplex (TDD), and spectrum of up to 100 GHz.[25] The core technologies of 5G are illustrated in Figure 2. While these data rates promise exceptionally fast loading of websites, apps and videos, they also place a significant bandwidth burden on network providers.

---

[24] See Table 8 in Appendix 1 which estimates sales revenues for all GPS devices in 2015. Verizon reported $91.7 billion in wireless revenues in 2015. (See, Verizon Communications, Inc. (2015) Annual Report 2015, https://www.verizon.com/about/sites/default/files/annual/verizon-annual-2015/downloads/15_vz_ar.pdf). $91.7billion over the year equates to $251 million per day, or $10.5 million an hour

[25] See, Letter from Ani Gevorkian to Marlene H. Dortch, GN Docket No. 14-177 (January 13, 2016), Reed Hundt, "The Future of Wireless Broadband: 5G, A Presentation for the Federal Communications Commission", January 2016, p.2, http://apps.fcc.gov/ecfs/document/view?id=60001404361.

Figure 2: 5G Core Technologies

Evolved Multi-Antenna Processing Very Large or Massive MIMO Systems	New Modulation and Coding Non-Orthogonal Multiple Access	New Access to Spectrum Unlicensed, Licensed Shared Access, cmW, mmW	Low Energy Systems Devices and Infrastructure
Coordinated Systems C-RAN Topologies and Silicon Photonics	Network Virtualization Software Defined Network	Multi-RAT Operation Intelligence Traffic Routing	Device-Device Communications MTC and V2V Applications

Source: See note 2, *supra*.

Thus, to meet these larger bandwidth needs, 5G envisions significant densification of existing networks through the addition of more abundant higher frequencies (traditionally not directly incorporated into mobile broadband networks) in massive small cell deployments. However, in addition to these improvements and conventional, human-centric mobile broadband communication, 5G will also exhibit sufficient reliability, scale, and latency to support both massive machine type communication (mMTC) and ultra-reliable machine type communication (uMTC) in real-time: driverless cars and smart grid, for example. By allowing for the rapid convergence of computing and communication, 5G will be a key enabling factor behind proliferation of next-generation IoT and improvement in economic productivity and the quality of life.

5G is not only about wireless networks delivering faster speeds but also promises a more connected world that enables the Internet of Things. As one of the use cases of 5G,[26] IoT refers to the linking and communication between physical objects, such as home appliances, autonomous systems, roadways and buildings, using "wired and wireless networks, often using the same IP

[26] Other use cases include Ultra High Definition, Tactile real-time control, Augmented reality, Connected health and Transport system.

that connects consumers to the Internet."[27] Simply put, this is the concept of connecting any device with an on and off switch to the Internet (and/or to each other).[28] By 2020 there could be over 26 billion connected devices, with some estimates ranging as high as 100 billion - "anything that can be connected, will be connected."[29] The full economic impact (including consumer surplus) of IoT is estimated to range between $3.9 trillion and $11.1 trillion in 2025, and customers (businesses and consumers) are expected to capture as much as 90% of the value generated by IoT applications.[30] Figure 3 illustrates areas in which IoT is expected to have the most impact. Consumers will capture benefits of IoT through lower cost of goods and services, greater convenience and time savings. As IoT-enabled optimization of day-to-day operations, transportation, energy utilization and equipment maintenance lowers operating costs for manufacturers and service providers, some of those savings will be passed directly to consumers.[31]

---

[27] See, Michael Chui, Markus Löffler, and Roger Roberts, "The Internet of Things," McKinsey Quarterly, March 2010, accessed May 2, 2016. http://www.mckinsey.com/industries/high-tech/our-insights/the-internet-of-things.

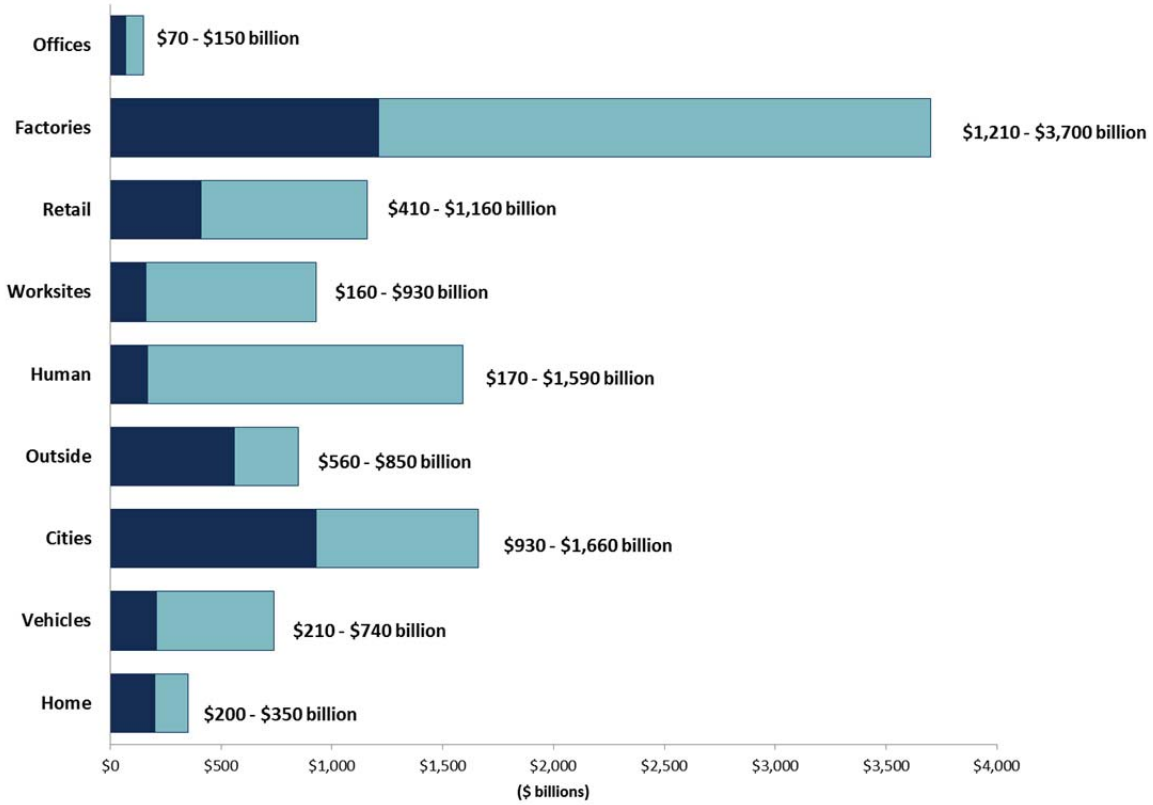
[28] See, Jacob Morgan, "A Simple Explanation of 'The Internet of Things,'" Forbes, May 13, 2014, accessed May 2, 2016, http://www.forbes.com/sites/jacobmorgan/2014/05/13/simple-explanation-internet-things-that-anyone-can-understand/#1c732b186828.

[29] See, Jacob Morgan, "A Simple Explanation of 'The Internet of Things,'" Forbes, May 13, 2014, accessed May 2, 2016, http://www.forbes.com/sites/jacobmorgan/2014/05/13/simple-explanation-internet-things-that-anyone-can-understand/#1c732b186828.

[30] See, McKinsey Global Institute, *The Internet of Things: Mapping the Value Beyond the Hype*, June 2015, p. 7, http://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Business%20Technology/Our%20Insights/The%20Internet%20of%20Things%20The%20value%20of%20digitizing%20the%20physical%20world/Unlocking_the_potential_of_the_Internet_of_Things_Executive_summary.ashx .

[31] In addition, driverless cars and IoT-managed public transportation will reduce commute time and stress affiliated with traffic congestion. Smart appliances will use IoT to help automate mundane home-maintenance tasks like lawn mowing or curtain drawing. For example, see Husqvarna's 400 Series Automower® (See, Husqvarna Robotic Lawn Mowers, accessed May 13, 2016, http://www.husqvarna.com/us/products/robotic-lawn-mowers/) or Loxone's Smart Home Systems (See, Loxone Smart Home, accessed May 13, 2016, http://www.loxone.com/enen/smart-home/everything-managed/curtains-and-blinds/curtains.html.)

Figure 3: Estimated Economic Value of IoT Applications in 2025



Source: McKinsey Global Institute, *The Internet of Things: Mapping the Value Beyond the Hype*, June 2015, p. 7, http://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Business%20Technology/Our%20Insights/The%20Internet%20of%20Things%20The%20value%20of%20digitizing%20the%20physical%20world/Unlocking_the_potential_of_the_Internet_of_Things_Executive_summary.ashx

Notes:

Home: living spaces, apartments and buildings; Vehicles: systems inside vehicles; Cities: urban environments; Outside: between urban environments; Human: devices attached to or implanted into human body; Worksites: custom production environments; Retail: spaces where consumers conduct commerce; Factories: standardized production environments; Offices: knowledge-worker working spaces.

2. Productive Use of Ligado's Terrestrial Spectrum

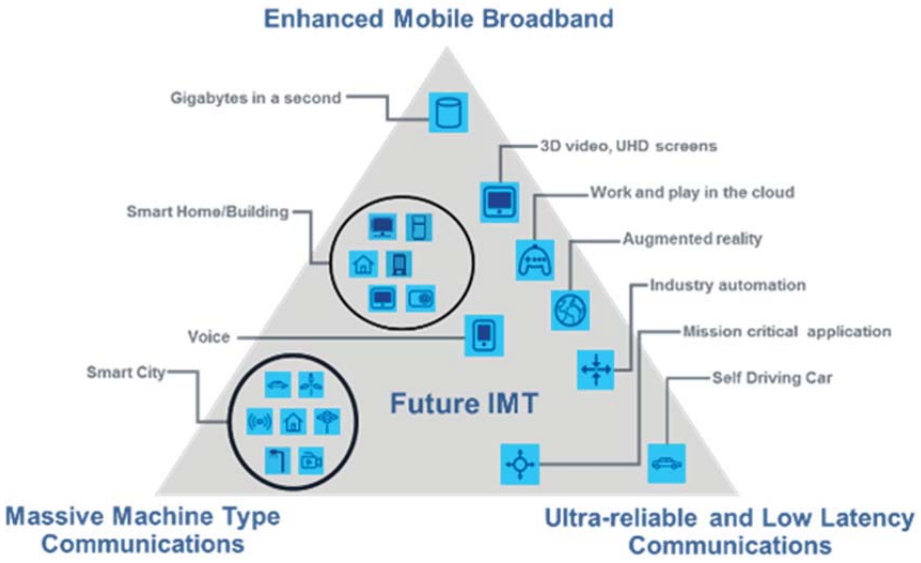
As discussed above, the mobile industry is preparing for its next generation of wireless technology, 5G, which promises higher-speed wireless networks and a new foundation to connect everything, supporting the Internet of Things. 5G will require access to large amounts of spectrum at a time when wireless networks are straining to meet the demand for mobile broadband.[32] Thus, the efficient use of licensed spectrum will become even more important with the development of the wireless industry.

Different 5G usage scenarios have different spectrum requirements. Figure 4 shows the three main usage scenarios of 5G. Enhanced Mobile Broadband (eMBB) drives multi-gigabit peak rates that do not necessarily need very large range but would require very large channel bandwidth, which are easier to find at higher frequencies, e.g., mm-wave. Conversely, ultra-reliable, low latency communications (uMTC) would require propagation characteristics that support in-building and wide-area coverage. So, for these scenarios, lower frequencies such as those below 2 GHz—such as the 1.5 GHz band spectrum—might be a better choice. Also, Massive Machine Type Communications (mMTC) could require greater range for applications, such as distributed sensor networks, where lower frequencies, e.g., those below 1 GHz, could be ideal.

---

[32] Technologies for mobile broadband and related services have traditionally operated best in frequencies below 3 GHz (3000 MHz). See, Bazelon, Coleman and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the U.S. Economy", May 11, 2015, p. 3, http://apps.fcc.gov/ecfs/document/view?id=60001117200. Next generation 5G technologies will be able to integrate higher frequency spectrum into the current mobile broadband networks, greatly increasing capacity in higher demand areas. The high frequency spectrum (with millimeter wave bands in the range of 24 GHz, 28 GHz, 37 GHz, 60 GHz and higher) were not viewed as suitable for mobile communications, but the amount of bandwidth available at higher frequencies is large and it supports very high data rates, thus is ideal to include in 5G. See, Tom Peters, "FCC Workshop Reveals Secrets of 5G", Focus on Regulation, Hogan Lovells, accessed on May 19, 2016, http://www.hlregulation.com/2016/03/15/fcc-workshop-reveals-secrets-of-5g/.

Figure 4: Main Usage Scenarios of 5G



Source: Recommendation ITU-R M.2083, "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond."

The mid-band spectrum (between 1 GHz and 2 GHz) Ligado can offer is scarce. Although there are large bandwidths available at high frequency spectrum such as millimeter wave, such high frequency is only appropriate for densification but not for wide area deployment. In order to serve the 5G uMTC use cases, a next-generation mobile network build needs to be anchored in mid band. Thus, Ligado's mid-band spectrum can serve as an ideal foundation to enable highly-secure and ultra-reliable 5G use cases that can only be supported by a next-generation mobile network.

3. The FCC's Policy Choice

Spectrum is allocated by the government for the benefit of the public.[33] Together, the FCC and the National Telecommunications and Information Administration ("NTIA") determine where and how each set of radio frequencies can be used with the FCC responsible for all non-federal

[33] See, Steve Waldman, "The Information Needs of Communities", Washington, D.C.: Federal Communications Commission, July 2011, p. 280, https://transition.fcc.gov/osp/inc-report/The_Information_Needs_of_Communities.pdf.

users and the NTIA responsible for federal users.[34] Over the past 30 years, the FCC, often working in conjunction with the NTIA, has made an estimated 645.5 MHz of licensed spectrum available for the mobile wireless industry.[35] As indicated earlier, there is still significant demand for additional frequencies to meet the growing demand for wireless capacity.[36]

Ligado's effort to make more productive use of its L-Band spectrum is the latest example in a long line of spectrum reallocations that exemplify the FCC's policy objectives of making more efficient use of the nation's spectrum resources. The FCC has long understood that allowing spectrum to be put to its highest valued uses is one way it fulfills its mandate to serve the public interest. In doing so, it has often made difficult decisions—as with the original PCS allocations—that weigh the benefits of additional spectrum for mobile wireless uses against the costs to the then existing users that would be displaced. More recently, the Commission has increasingly recognized that welfare is maximized and the public interest best served when spectrum is shared—as with the recent AWS 3 allocation that accommodates some federal users during a transition period and others permanently. In the L-Band, facilitating the coexistence of Ligado and its GPS neighbors clearly maximizes public welfare by making the most use of the scarce spectrum resources under an innovative approach that allows for terrestrial use of Ligado's spectrum while preserving GPS systems and protecting GPS consumer end users.

---

[34] The FCC manages the use of commercial spectrum through a combination of licenses and rules: it provides commercial licenses for mobile broadband, broadcast TV and radio, and satellite communication spectrum use; and sets rules that require unlicensed users to operate within a certain set of technical parameters in order to manage interference for near-range and low power services, such as WiFi, wireless mics, cordless phones, Bluetooth devices, and baby monitors. The NTIA, assigns spectrum to federal agencies, such as to DOD for radar, FAA for flight communication, and a wide variety of other uses such as weather balloons, GPS and other satellite communications. See, "Radio Spectrum Allocation", FCC, https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation.

[35] See, Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the American Economy", Prepared for CTIA – The Wireless Association, May 11, 2015, p. 1, http://apps.fcc.gov/ecfs/document/view?id=60001117200.

[36] See, Coleman Bazelon and Giulia McHenry, "Substantial Licensed Spectrum Deficit (2015-2019): Updating FCC's Mobile Data Demand Projections," Prepared for CTIA – The Wireless Association, June 23, 2015, pp. 2-8, http://apps.fcc.gov/ecfs/document/view?id=60001117199.

Accommodating new uses for spectrum is difficult because usually some users will have to alter their existing operations. In the original PCS allocations, existing microwave users had to relocate to alternative bands. The more recent AWS 1 and 3 allocations required various federal users to relocate their operations, while in the case of the AWS 3 allocation, others were accommodated in a permanent sharing regime. The 700 MHz band was reclaimed from television broadcasters as a result of their transition to digital broadcasting, but that transition was hastened through legislative action to make the frequencies available sooner. Even the upcoming voluntary Incentive Auction requires significant compensation to broadcasters to relinquish their broadcast licenses or move their transmissions to an alternative channel in order to make way for more wireless broadband users in the reclaimed frequencies. All of these reallocations shared the feature that an incumbent user had their use displaced.

Ancillary Terrestrial Component (ATC) authority for Mobile Satellite Service (MSS) licensees, by contrast, does not displace an existing user. Rather it is purely additive in the uses of the spectrum. As described above, Ligado's plan includes both terrestrial and satellite mobile uses, often integrated into a seamless offering. But Ligado's requested use does require sharing of the L-Band between Ligado and its GPS neighbors. Accommodating such sharing is the right choice for the FCC for at least two reasons.

First of all, it maximizes total societal benefits. As detailed below, the thriving GPS industry will not be adversely impacted, so the major costs of the transition to an L-Band sharing regime are borne by Ligado. The benefits of permitting both satellite and terrestrial use of Ligado's spectrum are significant. The fact that Ligado is offering to incur these costs is testimony that the value created exceeds these costs. Ligado's efforts to achieve voluntary agreements with GPS industry players reinforce that sharing the L-Band is welfare enhancing. In the economist's language, sharing the L-Band is a Pareto improving policy because it makes at least one entity better off without making anyone worse off. Society stands to gain without any users losing.

Facilitating sharing in the L-Band also avoids a worse outcome. If the FCC were to impose overly restrictive out of band emissions or further power restrictions (beyond those agreed to on a mutual basis under the Ligado-GPS co-existence agreements), it would do unnecessary harm to the public interest since those additional restrictions would burden spectrum usage and yet not generate additional protections for GPS users. As demonstrated through the RAA testing, the voluntary industry agreements between Ligado and GPS set power restrictions that protect GPS users. Any limits more restrictive than those proposed in the FCC's Public Notice would not create any added benefits or protections to GPS consumers, but would create harm by unnecessarily restricting Ligado's uses of its licensed spectrum. Such a policy decision would leave significant 'money on the table' in the form of unrealized benefits from terrestrial deployment of a desperately needed additional 40 MHz of mid-band spectrum.

The FCC has always chosen to move spectrum allocations toward more efficient uses. Facilitating sharing of L-Band spectrum between Ligado and its GPS neighbors is clearly the FCC's policy choice that continues this long tradition of improving the nation's welfare through its spectrum policies.

IV. The Proposed License Modifications Minimize Harm and Allows GPS and Ligado to Co-Exist

A. The Modification Applications

There are numerous factors that demonstrate that both the GPS industry and Ligado are aligned in their support for the Modification Applications, including: i) the Modification Applications' alignment with Ligado's settlements with GPS device manufacturing leaders;[37] and ii) the potential that the modifications will enhance GPS functionality.

The Modification Applications enable Ligado to deploy mid-band spectrum while addressing GPS industry concerns that arise because of the spectrum's proximity to the GPS allocated spectrum. Generally speaking, a receiving system in one band can tolerate a certain amount of wireless energy transmitted in neighboring bands before the quality of its service is degraded by a neighbor's "interference."[38] The degree of interference that can be tolerated by any given system is also influenced by the characteristics of its own receiving and transmitting equipment.[39] Thus, as illustrated in Figure 5 below, although the peak for each user's signal is

---

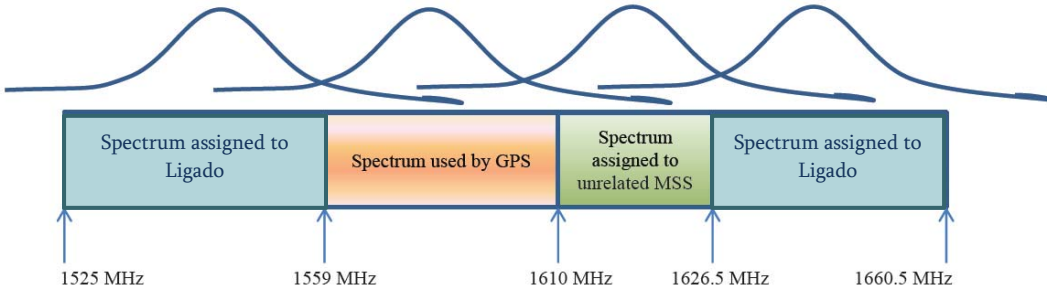
[37] Section IV.B details how leading GPS device manufacturers are representative of the GPS industry.

[38] Two wireless systems can operate simultaneously in the same area by using different frequencies. Each transmitter broadcasts on its designated frequencies, and their respective receivers tune to those frequencies, filtering out signals on other frequencies. If the filtering does not reject signals on other frequencies sufficiently well, the device may be unable to operate as designed. Interference can be mitigated by spacing out services in frequency or by using more-frequency selective receivers. (See, Jean Pierre De Vries and Phil Weiser, "Unlocking Spectrum Value Through Improved Allocation, Assignment and Adjudication of Spectrum Rights", March 24, 2014, SSRN: http://ssrn.com/abstract=2416428 or http://dx.doi.org/10.2139/ssrn.2416428.)

[39] See, Letter from Henry Goldberg, Attorney for LightSquared, to Marlene H. Dortch, Secretary, FCC, June 23, 2011, attaching Bazelon, C. June 22, 2011. The Brattle Group, "GPS Interference: Implicit Subsidy to the GPS Industry and Cost to LightSquared of Accommodation", http://licensing.fcc.gov/myibfs/download.do?attachment_key=898649.

centered within its own assigned spectrum, each user inevitably sends some signal into each neighbor's spectrum. Though one cannot reduce signal spillover to zero, one can reduce the spillover to an amount small enough that normal uses are not interrupted or "interfered" with.

Figure 5: Simplified Depiction of Spectrum Inference



In effect, the potential interference issues for GPS receivers are a consequence of existing GPS design—that is, because existing GPS devices do not filter spectrum from adjacent spectrum bands.[40] Efforts by Ligado over the past year have resulted in significant progress to establish consensus technical parameters for Ligado's terrestrial operations to co-exist with, and therefore not impact, the functionality of GPS devices that use the signals from GPS in adjacent bands. Ligado has proactively sought comment on whether Ligado's deployment would cause interference with GPS devices and has consulted with leading GPS device manufacturers to formulate the Modification Applications.[41]

---

[40] See, Letter from Henry Goldberg, Attorney for LightSquared, to Marlene H. Dortch, Secretary, FCC, June 23, 2011, attaching Bazelon, C. June 22, 2011. The Brattle Group, "GPS Interference: Implicit Subsidy to the GPS Industry and Cost to LightSquared of Accommodation", http://licensing.fcc.gov/myibfs/download.do?attachment_key=898649. GPS users have acknowledged that there is no problem with out-of-band emissions. See, Letter from Catherine Wang, Counsel to Deere & Co., to Marlene H. Dortch, Secretary, FCC, IBFS File No. SAT-MOD- 20101118-00239. March 21, 2011, at 10, http://licensing.fcc.gov/myibfs/download.do?attachment_key=877871.

[41] *Comment Sought on Ligado's Modification Applications,* IB Docket Nos. 11-109 and 12-340, April 22, 2016, Public Notice (DA 16-442), pp. 4-7.

More specifically, the Modification Applications are consistent with Federal Aviation Administration ("FAA") requirements[42] and settlement agreements entered into with three leading GPS manufacturers: John Deere and Co. ("Deere"), Trimble Navigation Limited ("Trimble") and Garmin International Inc. ("Garmin").[43]

The Modification Applications propose that the FCC should rescind the terrestrial authorization to the 10 MHz of spectrum that is closest to the adjacent GPS receivers and operate in three 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 than currently authorized.[44] Separately, Ligado has also proposed that the FCC auction the 5 MHz of government spectrum for commercial use that would require the license holder to share with the National Oceanic and Atmospheric Administration (NOAA) as additional downlink spectrum.[45]

Together, these operating parameters (summarized in Table 1 below), along with the spectrum leased from Crown Castle and potentially acquired through auction of NOAA spectrum operationalize a plan through which Ligado can deploy a total of 40 MHz of spectrum (20 MHz of downlink and 20 MHz of uplink spectrum) without causing interference to GPS users.

---

[42] Although the specific FAA parameters have not yet been determined, Ligado has agreed to condition its license on compatibility with FAA technical standards. "To protect certified aviation GPS devices, Ligado proposes 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." See, *Comment Sought on Ligado's Modification Applications,* April 22, 2016, IB Docket Nos. 11-109 and 12-340, Public Notice (DA 16-442), pp. 5-6.

[43] For additional detail on these settlement agreements, see Appendix 2.

[44] Ligado submitted new applications to modify the ancillary terrestrial component (ATC) of its L-band mobile satellite on December 31, 2015, and withdrew a prior request filed in 2012. See, *Comment Sought on Ligado's Modification Applications,* April 22, 2016, IB Docket Nos. 11-109 and 12-340, Public Notice (DA 16-442).

[45] See, *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*, April 22, 2016, RM-11681, Public Notice, DA-16-443.

As reported below, manufacturers Garmin and Deere do not object to any of the parameters specified in the Modification Applications.[46] Trimble jointly recommends and supports all parameters specified in the Modification Applications except one, the lower downlink.[47]

Table 1: Parameters of Modification Applications

			Modification				GPS Manufacturer Agreement		
	Band		Relinquish	Lower Power Limits	Tighter OOBE Limits	Tighter Narrowband OOBE Limits	Deere	Garmin	Trimble
[1]	**1526-1536 MHz**	**[Lower Downlink]**		x	x	x	x	x	
[2]	**1545-1555 MHz**	**[Upper Downlink]**	x				x	x	x
[3]	**1627.5-1637.5 MHz**	**[Lower Uplink]**		x	x	x	x	x	x
[4]	**1646.5-1656.5 MHz**	**[Upper Uplink]**		x	x	x	x	x	x

Source: See, Applications of LightSquared Subsidiary LLC, Narrative, IBFS File Nos. SAT-MOD-20151231-00090, SAT-MOD-20151231- 00091, and SES-MOD-20151231-00981, which includes a "Description of Proposed Modification and Public Interest Statement"; Deere, Garmin, and Trimble Agreements.

Furthermore, by codifying power modifications for all GPS manufacturers and clearing the way for the development of augmented precision in GPS functionality, the Modification Applications benefit the GPS industry overall.[48] That is, the Modification Applications, if adopted, guarantee

---

[46] See, Letter from Gerard J. Waldron to Marlene H. Dortch, IB Docket No. 12-340 (Dec. 8, 2015), accessed February 2, 2016, http://apps.fcc.gov/ecfs/document/view?id=60001352936 (Hereafter "Deere Agreement"); and Letter from Gerard J. Waldron to Marlene H. Dortch, IB Docket No. 12-340 (Dec. 17, 2015), accessed February 2, 2016, http://apps.fcc.gov/ecfs/document/view?id=60001388035 (Hereafter "Garmin Agreement").

[47] See, Letter from Gerard J. Waldron to Marlene H. Dortch, IB Docket No. 12-340 (Feb. 3, 2016), accessed February 4, 2016, http://apps.fcc.gov/ecfs/document/view?id=60001422644 (Hereafter "Trimble Agreement").

[48] Ligado's value as a complementary asset to the evolution of 5G has the potential to introduce additional benefit to GPS and its consumers by improving the precision and accuracy of signals. Recently at the 2016 Mobile Carriers Show, Ligado's Chief Technical Officer Tamara Casey, stated "we are evaluating things like what we can do in terms of a terrestrial augmentation of GPS and different

Continued on next page

interference-free reception of GPS signals going forward. Regulatory uncertainty always makes investments more risky. All GPS manufacturers operate with uncertainty about the outcome of the FCC's proceedings regarding Ligado. Resolving that uncertainty, especially as proposed in the FCC's Public Notice in a way that does not harm GPS manufacturers or users, increases the expected returns to investments in the GPS industry.

B. No Evidence of Cost to the Majority of the GPS Industry

1. GPS Usage

Spectrum assigned for GPS is used by Government owned and operated satellites that transmit signals directly to GPS receivers. GPS receivers range from simple handheld navigation devices to high-precision GPS devices used in airplanes and construction equipment, but they all take signals from at least 3 different satellites to triangulate the receiver's position. The government has also made efforts to encourage commercial users to take advantage of the GPS satellite network, bolstering development of commercial GPS devices and applications in the market – such as car navigation, portable navigation devices (PNDs) and converged devices (e.g., mobile and smart phones with GPS), shipment tracking and machine control, and agricultural uses. Currently, the commercial uses of GPS utilize single-frequency signal yielding lower accuracy than dual-frequency military signals.[49] However, the accuracy of commercial GPS signal can be substantially enhanced with the help of terrestrial network.[50] Military grade federal uses are not

---

Continued from previous page

types of GPS receivers implemented in our devices that will take accuracy from meters to centimeters." If deployed, better precision and accuracy would be a benefit to the GPS industry through the additional service offerings it can provide. Tamara Casey comments at the 2016 CCA Mobile Carriers Show, April 14, 2016.

[49] As a part of the GPS system upgrade, the US Government is fielding three new signals designed for civilian use. These are expected to gradually enter service between 2018 and the late 2020s. While the current, single-frequency civilian GPS signal is unable to correct for ionospheric propagation delay leading to degradation in accuracy, the availability of multiple-frequency GPS signals will significantly enhance civilian use accuracy. GPS.GOV, "New Civil Signals", accessed May 16, 2016, http://www.gps.gov/systems/gps/modernization/civilsignals/.

[50] For example, the US Coast Guard Navigation Center has been operating the Nationwide Differential GPS (DGPS) service with reduced positional error in Low- and Mid- frequency range. U.S.

Continued on next page

likely to be adversely impacted by transmission in adjacent spectrum because of robust battlefield designs; other federal uses rely on commercial devices.[51] Therefore, I focus on six broad commercial GPS categories, which consist of 15 applications (see Table 2):

1. The Aviation category is composed of devices installed in general aviation and commercial aircraft that enable three-dimensional position determination for aircraft in flight or during takeoff and landing. These devices are typically certified by the FAA, whereas handheld devices are not.

2. The High Precision ("HP") category is composed of surveying devices with GPS receivers used to gather data for the modeling and documenting of the physical world that can be displayed on maps and used in geographic information systems (GIS); agricultural devices with GPS receivers used in precision farming for applications such as farm planning, field and yield mapping, soil sampling, and tractor guidance; and construction devices with GPS receivers used on construction equipment for navigation, asset tracking, and fleet management. HP devices typically achieve accuracy levels within a few centimeters through the use of external augmentation signals that are provided either via satellite or through terrestrial radio links.

3. The General Location/Navigation ("GLN") category is composed of portable navigation devices ("PNDs") used in motor vehicles that are aftermarket electronic systems designed to provide location information and directions to a destination; wearable and outdoor devices that function as personal navigation and lifestyle devices, including those used for cycling, hiking, golf, and smart watches; other GLN devices used for asset tracking and marine navigation; and non-certified handheld navigation devices for aviation.

Continued from previous page

Department of Homeland Security United States Coast Guard, "Navigation Center – NDGPS General Information", accessed May 16, 2016, http://www.navcen.uscg.gov/?pageName=dgpsMain. Companies like Locata in Australia use terrestrial radio signals to either complement or substitute for GPS signals. Locata, "The Company," accessed May 16, 2016, http://www.locata.com/about/the-company/,.

[51] Designed to be jamming-resistant, military GPS signals can transmit at higher power and are generally much less susceptible to interference. Federal users receiving these signals will not be impacted by Ligado's operations in adjacent frequency bands. (Barker et al., "Overview of the GPS M Code Signal," MITRE Corporation Report, 2006, accessed May 23, 2016, http://www.dtic.mil/docs/citations/ADA456656,.)

4. The Cellular category is composed of smartphones and tablets with cellular network access and an operating system capable of providing location and navigation via network-assisted GPS.

5. The Auto category is composed solely of in-dash car navigation devices that are factory installed units designed to provide navigation—sometimes as part of a multi-function infotainment system.

6. The Timing category is composed of timing devices for networks which have GPS receivers that decode the time dimension of GPS signals, synchronizing the receiver's time to the satellites' atomic clocks. Such devices are typically used to supply the precise time to communication systems, electrical power grids, and financial networks.

Table 2: List of GPS Device Categories and Applications

Category	Application	Use
Aviation	General Aviation ("certified") Commercial Aviation ("certified")	Industrial
High Precision ("HP")	Surveying Precision Agriculture Heavy Construction/Earth Moving	Industrial
General Location/Navigation ("GLN")	Portable Navigation Device ("PND") Handheld Aviation ("non-certified") Marine Navigation (integrated) Marine Navigation (handheld) Wearables Outdoor and Fitness Asset Tracking	Consumer
Cellular	Tablets Smartphones	Consumer
Auto	In-dash	Consumer
Timing	Timing for Networks	Industrial

These devices all have functional elements that rely on information from signals from the constellation of GPS satellites, although the relative importance of this GPS functionality to the overall value may vary, depending on their applications. And these devices are put to different uses. Aviation, high precision, and timing devices have industrial uses while general location navigation, cellular, and auto are predominantly used by consumers. Within these respective

categories, Garmin has a large share of non-cellular consumer devices, and Trimble and Deere have large shares of industrial devices.[52]

Figure 6 shows that consumer GPS devices (cellular, general location navigation, and auto devices), account for more than 99 percent of all GPS devices installed as of 2015, and that over 40 percent[53] of the remaining GPS devices are manufactured by Deere, Trimble and Garmin - GPS stakeholders which, as noted above, collaborated with Ligado in specifying the Modification Applications.[54]

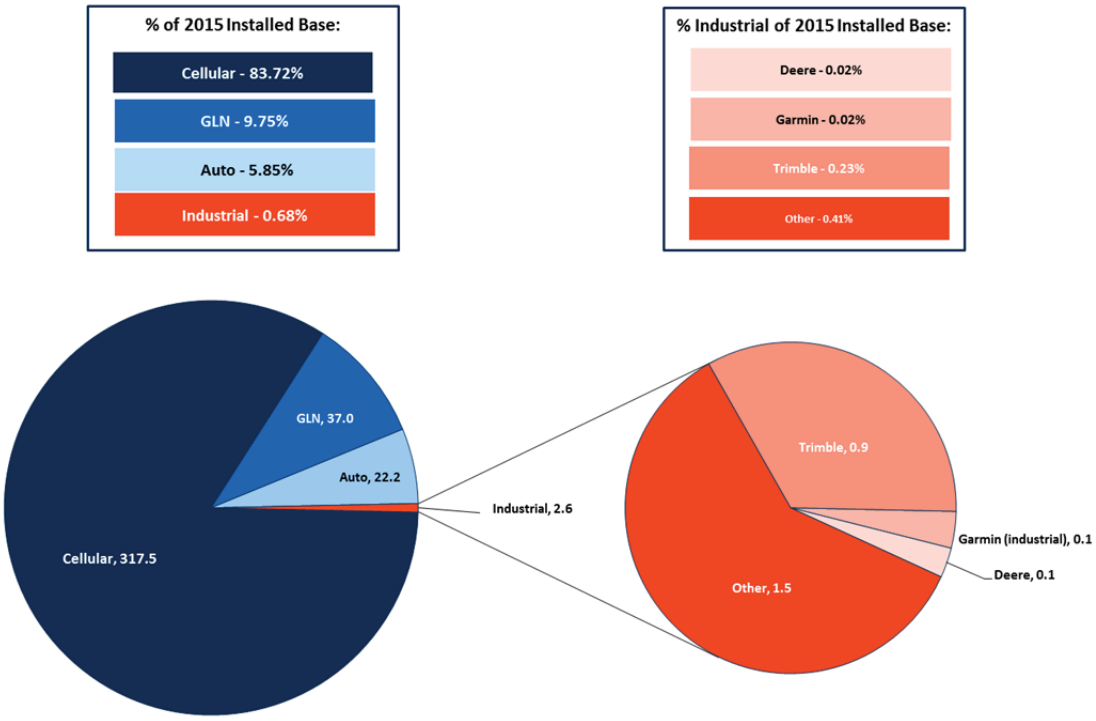
---

[52] See Table 9 in Appendix 1.

[53] As shown in Table 9 in Appendix 1, Deere, Garmin, and Trimble have a collective market share of 71, 51, and 35 percent for the certified aviation, HP, and timing devices categories respectfully.

[54] See Appendix 2.

Figure 6: Breakdown of 2015 Installed Base (millions of units)



Sources and Notes: See Table 5 in Appendix 1. Garmin industrial devices only include Garmin aviation devices. All other Garmin devices are included under GLN and Auto.

2. Evidence of Only Minor Costs to GPS Industry

Ligado has commissioned extensive testing to ensure that GPS devices would not experience harmful[55] interference with the adoption of the Modification Applications. In order to assess the potential risk of loss of device functionality from interference associated with the deployment of Ligado's network, Ligado engaged the technology and radio frequency spectrum management

[55] Specifically, in accordance with the FCC's standards, RAA tested if Ligado's proposed terrestrial broadband operations would cause "harmful interference" to GPS devices. "Under this standard, 'harmful interference' to a GPS device would be interference that endangers or seriously degrades the ability of the GPS device to measure and accurately report the data the device is designed to provider to users: principally, the device's position." *Roberson and Associates*, "Results of GPS and Adjacent Band Co-Existence Study," May 9, 2016, pp. 3-4. ("RAA Report")

firm Roberson and Associates ("RAA") to perform a series of interference tests, which were submitted to the FCC on May 9, 2016. RAA intentionally chose to test devices that were produced by some of the industry's largest manufacturers in order to capture as large a representation of the entire market as reasonably possible. As detailed below, testing results demonstrate that cellular and general location navigation are unaffected by Ligado's proposed operations under virtually all conditions. Taken together, the testing results and the GPS agreements with leading GPS manufacturers suggest that deployment of Ligado's spectrum will create no costs to most other GPS users.

Three device categories were not covered in the testing: certified aviation, auto in-dash, and timing devices. FAA-certified aviation compatibility is required by the Modification Applications; thus, any potential issues will be addressed prior to deployment of Ligado's operations. The power level will be established in such a manner that Ligado's operations will be consistent with all applicable FAA requirements, as set out in the FAA's Technical Standards Orders. It is my understanding that the power level will be determined only after evaluation by the FAA and the aviation community as part of its established spectrum consultation process, but that the power level for the lower downlink will be substantially lower than what is currently proposed in the license modification. This reduced power level will impose costs on Ligado (it will necessitate more base stations and/or foregone business opportunities) but will result in no costs or impact on certified aviation devices.

Furthermore, I understand that over the course of this proceeding, there has been no evidence presented of interference harm by in-dash device manufacturers. Prior to submission of Ligado's updated plan, the Alliance for Telecommunications Industry Solutions ("ATIS") submitted concerns about potential interference to timing devices and suggested additional testing was necessary. I understand that Ligado has undertaken additional testing.

3. RAA Testing Results

RAA's final test plan reflects feedback received from various device manufacturers and other interested parties including the National Public Safety Telecommunications Council and the Department of Transportation (DoT).[56] RAA completed testing under various signal conditions for 27 total device models: three cellular, eleven high precision, twelve GLN, and one handheld

[56] RAA Report, pp. 5-6.

non-certified aviation devices.[57] Table 3 below lists the devices that were tested by RAA and the extent to which each device model represents the device's entire market.

[57] RAA Report, pp. 6-7, 11-13. See also, Table 3 and RAA Report, Summary of Methods and Results.

Table 3: Estimated Percentage of 2016 GPS Installed Base Covered by RAA Testing

Categories	Applications	List of Devices Tested [a]	Low Estimate [b]	High Estimate [c]
High Precision	Surveying	Trimble Geo 7x; Trimble R8s Rover; Trimble Net R9	36%	70%
	Precision Agriculture	Trimble AgGPS 542; Topcon HiPer V; Topcon System 310; Topcon SGR-1; NovAtel Smart6	42%	45%
	Heavy Construction	Trimble SPS855 GNSS Receiver; Trimble SPS985 Antenna; NAVCOM SF-3050	40%	85%
	Total		**40%**	**68%**
GLN	PND	Garmin Nuvi 2495LMT; Garmin Nuvi 2597LMT; Garmin Nuvi 55LM	63%	84%
	Handheld Aviation	Garmin GPSMAP 696	14%	100%
	Wearables/Outdoor	Garmin eTrex H; Garmin Montana 650t	9%	17%
	Marine and Asset Tracking	Garmin GPSMAP 78 SC; Garmin GPSMAP 76 CSx; Trimble TM3000; Furuno GP32; Wabtec Navigation Sensor Module; Motorola MW810; Motorola APX 7000	11%	30%
	Total		**23%**	**37%**
Cellular	Tablets	Samsung Galaxy Tab 4G LTE	28%	35%
	Smartphones	Samsung Galaxy S5 and S6	23%	29%
	Total		**24%**	**31%**

Sources and Notes:

[a]: RAA Report, Summary of Methods and Results.

[b]: The low estimate is calculated by estimating the portion each manufacturer's sales of a given application that are attributable to the devices tested and then multiplying by the manufacturer's overall share of the application.

[c]: The high estimate assumes that if at least one of the manufacturer's applications within a category were tested, then all of the manufacturer's devices within that category would be covered due to similarities in archetype designs within a category.

In addition to selecting devices that broadly represent the GPS market, RAA took an extremely conservative approach to measuring potential interference. Testing by the Working Group ("TWG") in 2011 demonstrated that 99 percent of the time GPS antennas receive power signals of less than i) -35 dBm in dense urban areas; ii) -20 dBm in urban areas; iii) -22.5 dBm in suburban; and iv) -24 dBm in rural areas. For its testing, RAA chose the most conservative

approach of these four environments and determined if GPS devices experienced any interference with power levels up to -20 dBm.[58]

The GPS devices tested by RAA fall into one of the following three categories: i) no interference as-is under any circumstance; ii) no interference under ordinary use; and iii) no interference subject to fully modified power operations or incorporation of upgraded component(s).[59]

1. No interference under any circumstance (no cost): all three cellular devices, eleven of twelve GLN devices, four of eleven high precision devices, and the only handheld aviation device experienced no significant impact using each device's current antenna and other components.

2. No interference under ordinary use (no cost): one high precision and one GLN device are not expected to experience interference under normal circumstances. Each device would rarely receive the high LTE power levels experienced in the testing environment given their uses.

3. No interference subject to fully modified power operations or incorporation of upgraded components (potential for modest cost): three high precision devices did not experience significant interference when the antennas in place were replaced with filtered antennas. The final three high precision devices experienced interference in the 1526-1536 MHz band; however, RAA's tests do not consider the power limits that Ligado has proposed over this band to be consistent with FAA requirements. It is my understanding that to the extent that the FAA sets sufficiently strong power limits, these devices will be compatible with Ligado's operations.[60]

RAA's tests demonstrate that the majority of GPS devices are compatible under their ordinary use today. As an initial matter, tests of the consumer device categories (cellular and GLN) show no harm from adjacent band operations. Although RAA was not able to test every device in these

---

[58] RAA Report, p. 10.

[59] RAA Report, pp. 11-13.

[60] According to RAA's testing, three Topcon high precision devices first experienced interference at powers of -34, -32, and -24 dBm. Although it is uncertain what power limits the FAA will set, it is reasonable to assume that the power limits will be lower than -34 dBm, thus ensuring compatibility. RAA Report, "Summary of Method and Results," p. 24.

categories, the devices that were tested as shown in Table 3 above were manufactured by Samsung, Garmin, and Trimble, each a major player in their respective categories. This indicates that RAA's test results are likely representative of all consumer devices (or approximately 93% of the entire commercial GPS market).[61] Moreover, the cellular testing results are consistent with previous testing conducted by the NTIA in 2012.[62] With respect to consumer GLN devices, Bill Alberth, a former Vice Chairman and CTO of Motorola, asserted that because Garmin is a market-leading firm, the settlement between Ligado and Garmin would cause a "ripple effect" resulting in other smaller GPS manufacturers soon purchasing upgraded consumer GLN devices through a common supply chain.[63] In effect, this indicates that newly manufactured consumer GLN devices would—and certainly could-- be fully compatible with Ligado's operations.

Within the industrial category, several devices showed no signs of interference as-is even under RAA's conservative approach while others only experienced interference at certain high power levels. As stated above, the likelihood of GPS devices receiving such high power signals is very low, especially considering many of these devices would be used in rural areas and that Ligado has proposed imposing power limits over this band to be consistent with FAA requirements. Ligado believes it is reasonable to expect that the FAA will set sufficiently strong power limits to prevent any potential interference for the three devices that could not have antennas replaced.[64]

The sooner the FCC acts, the faster any necessary power limits can be imposed in order to ensure compatibility of industrial devices with Ligado's operations. Should GPS manufacturers want to be extremely cautious and ensure compatibility at high power levels, RAA's results indicate that

---

[61] See Table 5 in Appendix 1.

[62] Letter from Lawrence Strickling to FCC Chairman Julius Genachowski, February 14, 2012, p. 3.

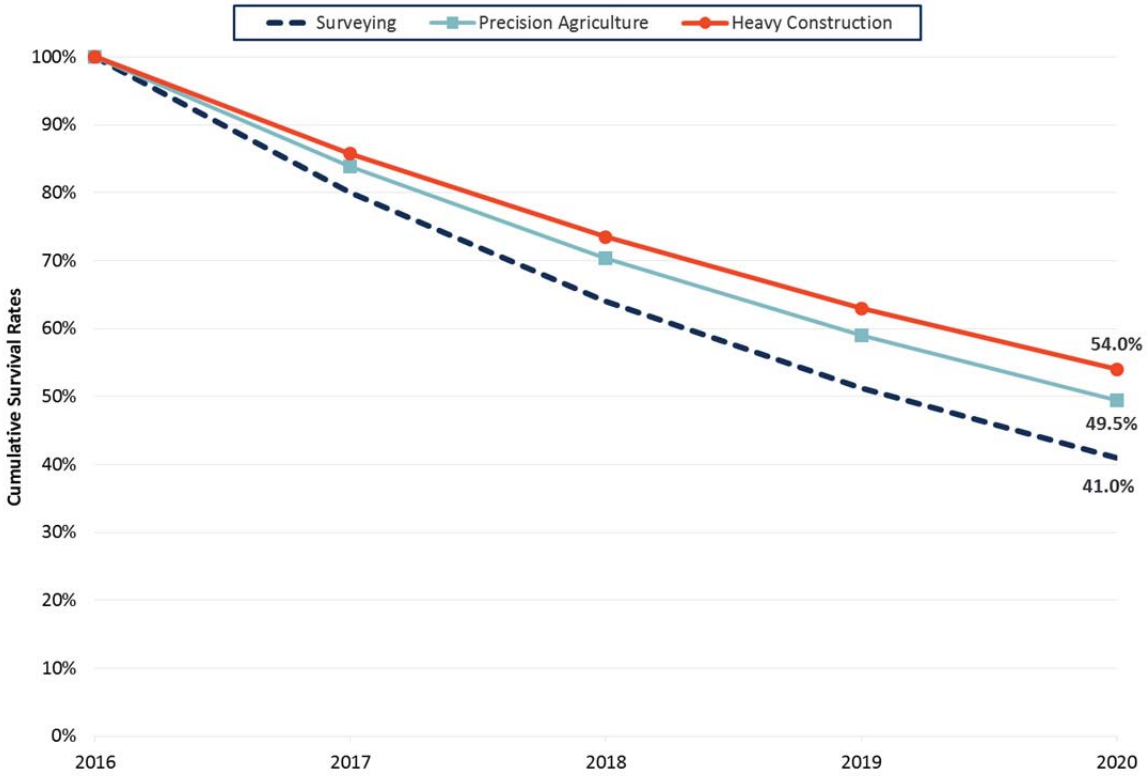
[63] "The GPS consumer device industry, to a large extent, shares a common supply chain and uses similar or identical GPS consumer device component parts, especially chipsets and filters. Given industry practices, other GPS device manufacturers will develop GPS consumer devices employing components (including antennas, filters, and receiver systems) that are identical or similar to the components used by Garmin. Consequently, the same operational limits on [Ligado] established by the Garmin-[Ligado] agreement will benefit other GPS consumer device manufacturers, resulting in a degree of operational compatibility equal to that secured by Garmin." Declaration of Bill Alberth in the Matter of GPS Industry Supply Chain, February 11, 2016, pp. 2-3.

[64] Letter from Covington and Burling, "Re: Written *ex parte* presentation in IB Docket No. 11-109; IBFS File Nos. SES-MOD-20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091," May 9, 2016, p. 4.

new devices can be enhanced at a negligible cost and older devices can be upgraded or replaced at a relatively small cost.[65] Due to natural device retirement, the portion of industrial devices that do not have enhanced receivers will become an increasingly small portion of the installed base over time. And the smaller the portion of these devices, the lower the cost. As an illustration, Figure 7 shows the percentage of high precision devices in the 2016 installed base that "survive" or remain in use in each subsequent year. For example, only 49.5% of the 2016 installed base of precision agriculture is expected to remain in use in 2020. Only a small subset of the 49.5% remaining may require upgraded components or replacement as denoted above. Thus, Ligado's operations will come at a minimal economic cost.

[65] Of the three largest high precision manufacturers, two (Trimble and Topcon) had multiple devices tested by RAA, and the other (Deere) has demonstrated acceptance of Ligado's proposed modifications through its settlement agreement. Together, devices sold by these three manufacturers account for over 75 percent of high precision devices as of 2015, indicating widespread compatibility in this category.

Figure 7. Percentage of 2016 Installed Base that Remains in Use (2016 – 2020)



Sources and Notes: See Table 6 in Appendix 1 for underlying retirement rates.

In summary, settlements with the major manufacturers Deere, Garmin, and Trimble, supply chain dynamics, the natural turnover of devices, and RAA test results indicate that under normal circumstances all consumer devices are not impacted and the few industrial devices that may be impacted under certain circumstances can be modified to provide resilience.

C. PLAN COSTS ARE BORNE BY LIGADO

The costs introduced by Ligado's proposed transition plan are predominantly several impairments to Ligado's spectrum holdings that will discount its value, including: i) costs associated with interference mitigation modifications; and ii) costs to acquire additional (downlink) spectrum.[66] These encumbrances ultimately increase Ligado's deployment costs as well as decrease its capacity and revenues. More specifically:

1. Power modifications in the downlinks (1526-1536 MHz Band)

- *The long term potential cost of impairment of this 10 MHz downlink is highly uncertain.*

2. Power modifications in the uplinks (1627.5-1637-5 MHz & 1646.5-1656.5 MHz Bands)

- *The long term potential cost of impairment of these 10 MHz uplinks is likely limited.*[67]

3. Relinquishment of downlink adjacent to GPS (1545-1555 MHz Band)

- *Based on the updated value of unencumbered AWS, wireless broadband spectrum is worth approximately $2.00 per MHz-Pop. This implies that the value of Ligado's 10 MHz of nationwide L band spectrum relinquished is approximately $6 billion.*[68]

---

[66] Since the expected value of radio spectrum licenses is driven by the present value of future expected cash flows from the services enabled, any factor that decreases the value of those expected cash flows has a negative effect on spectrum value.

[67] The power modifications on the uplinks, including the lower uplink, are relatively modest, and less likely to cause an impact than on the downlink. The unpaired spectrum sold in Auction 97 is designated uplink spectrum. Furthermore, since the limiting factor in spectrum availability and network capacity is generally downlink, the relative value of the uplink spectrum is more limited. See Coleman Bazelon, Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the American Economy", May 11, 2015, http://apps.fcc.gov/ecfs/document/view?id=60001117200.

[68] US population was approximately 309.3 million in 2010. Furthermore, Ligado is proposing to reduce its paired bandwidth. The unpairing and positioning of uplinks and downlinks is novel and the technology that it requires is specific for this use. As such, it is an added cost to develop the spectrum and would likely impair the spectrum's overall value. Because unpaired spectrum deployment typically requires substantially higher investment in new technology and infrastructure, all else equal, the economic value of unpaired spectrum is less than paired spectrum. See Coleman Bazelon, Giulia McHenry, "Spectrum Value", Telecommunications Policy, September, 2013. In past work, I have found that unpaired spectrum was sold at a 40 percent discount.

Continued on next page

4, NOAA spectrum (1675-1680 MHz Band)

- *Estimate from President's budget is $300 million.*

As described above, RAA testing indicates that the operations on the lower 10 MHz portion of Ligado's spectrum pose no meaningful risk to the users of over 99 percent of GPS devices.[69] More specifically, there are no costs associated with consumer devices and the potential costs associated with the impact to the GPS industry on a select number of non-consumer applications are expected to be modest. The costs identified here will facilitate the deployment of needed greenfield mid-band spectrum that will help facilitate 5G deployments, with their accompanying benefits to the U.S. economy and consumers.

Continued from previous page

[69] See Figure 6 above. As discussed earlier, testing identified potential interference issues for only a small subset of industrial devices may require upgraded components or power limitations. All industrial devices account for less than one percent of GPS devices.

Appendix 1. The Market for Commercial GPS Devices

The commercial GPS market model ("market model") estimates the size of the market for GPS-enabled devices in the United States across sixteen applications from 2015 through 2020 using three key metrics:

(1) the annual number of devices currently in use (*i.e.*, the stock of devices or "installed base");

(2) the annual number of devices sold; and

(3) the annual revenue generated by device sales.

I relied upon three types of sources to accurately size the market at the application and manufacturer level: (1) expert interviews; (2) publicly available government reports; and (3) analyst and industry reports publicly available for purchase.

A. Installed Base, Sales, and Retirements

The size of the installed base at the end of any given year depends on three components: (1) the size of the installed base at the end of the previous year; (2) the number of new units sold;[70] and (3) the number of units that retired.[71] To illustrate this relationship, I consider how the installed base of a specific GPS-enabled device evolves over time.

In each year, some share of the installed base of a particular device application will retire. I refer to this share as the retirement rate. Conversely, one minus the retirement rate is the survival rate - *i.e.*, the share of the installed base for a particular device application that does not retire. For example, if the installed base of a device of application type i in year t is X_{it}, the quantity of new sales is Q_{it}, and the retirement rate for such devices is r_i, then the installed base in year t will be

[70] Sales include new units (such as those installed on new airplanes) and replacement units (such as those installed on existing airplanes).

[71] Retirements broadly capture all devices, whether they're replaced or not, that have been voluntarily or involuntarily removed from the installed base.

$X_{it} = X_{it-1}(1 - r_i) + Q_{it}$. In other words, the current year's installed base is composed of new sales and those devices that survive from the previous year's installed base.

Table 4. Sales of GPS Devices by Application, 2015 – 2020 (thousands of units)

Categories	Applications	2015	2016	2017	2018	2019	2020
Aviation	General Aviation	6.20	6.30	6.40	6.43	6.48	6.57
	Commercial Aviation	0.47	0.49	0.51	0.51	0.50	0.50
	Total	**6.67**	**6.79**	**6.92**	**6.95**	**6.98**	**7.07**
High Precision	Surveying	32.44	34.27	36.34	38.66	41.26	44.18
	Precision Agriculture	26.95	26.95	33.68	33.68	33.68	33.68
	Heavy Construction	29.07	31.68	34.53	37.64	39.52	41.50
	Total	**88.45**	**92.90**	**104.55**	**109.98**	**114.46**	**119.36**
GLN	PND	5,250.00	4,670.00	4,200.00	3,910.00	2,500.00	2,500.00
	Handheld Aviation	12.94	12.98	13.04	13.07	13.11	13.18
	Marine Navigation (integrated)	182.09	185.73	189.45	193.24	197.10	201.04
	Marine Navigation (handheld)	297.50	303.45	309.52	315.71	322.02	328.46
	Wearables	5,515.79	12,860.90	14,396.50	15,533.05	16,265.77	17,033.07
	Outdoor and Fitness	1,150.33	1,196.69	1,244.93	1,295.11	1,347.31	1,401.62
	Asset tracking	1,445.43	1,783.64	2,205.02	2,731.55	3,391.59	4,221.86
	Total	**13,854.08**	**21,013.40**	**22,558.46**	**23,991.73**	**24,036.91**	**25,699.23**
Cellular	Tablets	34,463.00	40,127.54	42,997.60	44,948.46	47,077.82	48,631.41
	Smartphones	169,300.00	178,880.00	185,630.00	193,050.00	200,766.59	208,791.63
	Total	**203,763.00**	**219,007.54**	**228,627.60**	**237,998.46**	**247,844.42**	**257,423.04**
Auto	In-dash	4,835.54	5,648.28	6,500.68	7,125.80	7,828.18	8,603.44
Timing	Timing for Networks	194.60	197.18	199.76	202.34	204.92	207.50
Grand Total		**222,742.33**	**245,966.09**	**257,997.96**	**269,435.26**	**280,035.86**	**292,059.64**

Table 5. Installed Base of GPS Devices by Application, 2015 – 2020 (millions of units)

Categories	Applications	2015	2016	2017	2018	2019	2020
Aviation	General Aviation	0.12	0.12	0.12	0.12	0.12	0.12
	Commercial Aviation	0.01	0.01	0.01	0.01	0.01	0.01
	Total	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**
High Precision	Surveying	0.16	0.16	0.16	0.17	0.18	0.19
	Precision Agriculture	0.17	0.17	0.17	0.18	0.18	0.19
	Heavy Construction	0.19	0.19	0.20	0.21	0.22	0.23
	Total	**0.51**	**0.52**	**0.54**	**0.56**	**0.58**	**0.60**
GLN	PND	13.00	11.00	9.00	8.00	7.00	6.44
	Handheld Aviation	0.06	0.06	0.06	0.06	0.06	0.07
	Marine Navigation (integrated)	1.79	1.80	1.81	1.82	1.83	1.85
	Marine Navigation (handheld)	2.05	2.06	2.07	2.09	2.12	2.14
	Wearables	6.22	15.64	21.39	25.09	27.48	29.32
	Outdoor and Fitness	4.05	4.23	4.42	4.61	4.81	5.01
	Asset tracking	9.80	10.92	12.38	14.27	16.69	19.78
	Total	**36.97**	**45.71**	**51.14**	**55.95**	**60.00**	**64.60**
Cellular	Tablets	93.93	113.44	129.01	140.91	151.29	160.53
	Smartphones	223.61	234.46	243.21	250.27	256.80	263.46
	Total	**317.55**	**347.90**	**372.22**	**391.18**	**408.09**	**423.99**
Auto	In-dash	22.18	25.90	30.15	34.65	39.47	44.64
Timing	Timing for Networks	1.94	1.97	2.00	2.03	2.06	2.09
Grand Total		**379.28**	**422.14**	**456.17**	**484.51**	**510.33**	**536.05**

Table 6. Retirement Rates of GPS Device, 2015 – 2020 (%)

Categories	Applications	2015	2016	2017	2018	2019	2020
Aviation	General Aviation	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
	Commercial Aviation	6.7%	6.7%	6.7%	6.7%	6.7%	6.7%
High Precision	Surveying	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
	Precision Agriculture	16.1%	16.1%	16.1%	16.1%	16.1%	16.1%
	Heavy Construction	14.3%	14.3%	14.3%	14.3%	14.3%	14.3%
GLN	PND	54.4%	51.3%	56.4%	54.6%	43.8%	43.8%
	Handheld Aviation	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
	Marine Navigation (integrated)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
	Marine Navigation (handheld)	14.3%	14.3%	14.3%	14.3%	14.3%	14.3%
	Wearables	55.3%	55.3%	55.3%	55.3%	55.3%	55.3%
	Outdoor and Fitness	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
	Asset tracking	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%
Cellular	Tablets	18.8%	21.9%	24.2%	25.6%	26.0%	26.0%
	Smartphones	73.9%	75.1%	75.4%	76.5%	77.6%	78.7%
Auto	In-dash	8.7%	8.7%	8.7%	8.7%	8.7%	8.7%
Timing	Timing for Networks	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%

Sources and Notes: Annual implied retirement rates are used for PNDs, tablets, and smartphones given reliable estimates of units sold and the size of the installed base were available. All other devices apply a fixed retirement rate across all years based on expert interviews and industry reports.

In addition to tracking sales and the installed base of devices over time, I forecast gross annual revenues by application, estimated as the product of the average sales price ("ASP") and the annual quantity of devices sold. To estimate the ASP for each device as seen in Table 7 below, I reviewed publicly available information on manufacturer websites and industry reports, and consulted with industry experts.

With the exception of tablets and smartphones, where more manufacturer-level data were available, the ASP for a given application was assumed to be the same across manufacturers (*e.g.*, Precision Agricultural devices manufactured by Deere and Trimble were assumed to be sold at the same price). In addition, for certain devices such as certified general and commercial aviation devices, ASPs were assumed to be constant from 2015 to 2020. Other devices such as PNDs are expected to gradually decline in price due to decreasing demand.

Table 7. Weighted Average Sales Price, 2015 – 2020 ($ per device)

Categories	Applications	2015	2016	2017	2018	2019	2020
Aviation	General Aviation	$16,787	$16,787	$16,787	$16,787	$16,787	$16,787
	Commercial Aviation	$83,933	$83,933	$83,933	$83,933	$83,933	$83,933
High Precision	Surveying	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000
	Precision Agriculture	$15,015	$15,015	$15,015	$15,015	$15,015	$15,015
	Heavy Construction	$14,400	$13,824	$13,271	$12,740	$12,231	$11,741
GLN	PND	$125	$116	$107	$99	$91	$85
	Handheld Aviation	$1,119	$1,119	$1,119	$1,119	$1,119	$1,119
	Marine Navigation (installed)	$1,470	$1,470	$1,470	$1,470	$1,470	$1,470
	Marine Navigation (handheld	$300	$300	$300	$300	$300	$300
	Wearables	$457	$508	$517	$508	$503	$503
	Outdoor and Fitness	$354	$354	$354	$354	$354	$354
	Asset tracking	$335	$331	$327	$323	$317	$311
Cellular	Tablets	$376	$376	$376	$376	$376	$376
	Smartphones	$473	$473	$473	$473	$473	$473
Auto	In-dash	$603	$571	$543	$509	$492	$478
Timing	Timing for Networks	$1,328	$1,328	$1,328	$1,327	$1,327	$1,327

Sources and Notes: Average sales price is weighted by the market share of each manufacturer within an application type.

To estimate total gross revenues, I then multiply the manufacturer's market share (in sales) by its reported ASP and sum across all manufacturers within an application. This is summarized in Table 8 below.

Table 8. Gross Revenues from Sales of GPS Devices, 2015 – 2020 ($ millions)

Categories	Applications	2015	2016	2017	2018	2019	2020
Aviation	General Aviation	$104.07	$105.78	$107.48	$107.98	$108.76	$110.36
	Commercial Aviation	$39.07	$41.26	$43.17	$43.19	$41.83	$41.79
	Total	**$143.14**	**$147.04**	**$150.66**	**$151.16**	**$150.59**	**$152.15**
High Precision	Surveying	$356.79	$377.01	$399.71	$425.21	$453.83	$486.00
	Precision Agriculture	$404.59	$404.59	$505.74	$505.74	$505.74	$505.74
	Heavy Construction	$418.56	$437.98	$458.30	$479.57	$483.41	$487.27
	Total	**$1,179.94**	**$1,219.58**	**$1,363.76**	**$1,410.51**	**$1,442.97**	**$1,479.01**
GLN	PND	$655.59	$539.43	$448.75	$386.44	$228.55	$211.41
	Handheld Aviation	$14.48	$14.53	$14.60	$14.63	$14.67	$14.75
	Marine Navigation (integrated)	$267.75	$273.11	$278.57	$284.14	$289.82	$295.62
	Marine Navigation (handheld)	$89.25	$91.04	$92.86	$94.71	$96.61	$98.54
	Wearables	$2,519.39	$6,530.05	$7,440.03	$7,885.45	$8,174.38	$8,559.99
	Outdoor and Fitness	$407.34	$423.76	$440.84	$458.61	$477.09	$496.32
	Asset tracking	$484.55	$591.26	$721.64	$881.03	$1,075.95	$1,314.47
	Total	**$4,438.35**	**$8,463.16**	**$9,437.28**	**$10,005.00**	**$10,357.08**	**$10,991.09**
Cellular	Tablets	$12,944.05	$15,071.61	$16,149.59	$16,882.32	$17,682.09	$18,265.61
	Smartphones	$80,141.64	$84,676.53	$87,871.78	$91,384.19	$95,037.00	$98,835.82
	Total	**$93,085.70**	**$99,748.15**	**$104,021.37**	**$108,266.51**	**$112,719.09**	**$117,101.43**
Auto	In-dash	$2,914.09	$3,224.45	$3,528.53	$3,626.95	$3,853.42	$4,110.98
Timing	Timing for Networks	$258.49	$261.84	$265.20	$268.55	$271.91	$275.26
Grand Total		**$102,019.70**	**$113,064.22**	**$118,766.79**	**$123,728.69**	**$128,795.06**	**$134,109.93**

B. MARKET SHARES

For each device application, I gathered information about the market share of leading device manufacturers.[72] These market share estimates were then used to approximate the number of devices sold by each leading device manufacturer, as a share of the total installed base of a particular application type. Market shares were assumed to be stable over time across manufacturers and device applications. In 2015, the collective market share of Garmin, Deere, and Trimble was approximately 71, 51, 48, 8, and 35 percent for the certified aviation, HP, GLN,

[72] To estimate each manufacturer's share of device applications and categories, I relied upon segment-level manufacturer financials, industry reports forecasting sales and the size of the market for a given application, and consultation with industry experts.

auto, and timing devices, respectively (see Table 9). Notably, these three manufacturers are not market players in the cellular category, which is dominated by Apple and Samsung.[73]

Table 9: Market Share of Installed Base by Manufacturer (2015)

Category		Garmin [a]	Deere [b]	Trimble [c]	Combined [d]	Other [e]	Total [f]
Aviation	[1]	71.1%	0.0%	0.0%	71.1%	28.9%	100.0%
High Precision	[2]	0.0%	14.7%	36.7%	51.4%	48.6%	100.0%
GLN	[3]	48.0%	0.0%	0.0%	48.0%	52.0%	100.0%
Cellular	[4]	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%
Auto	[5]	7.7%	0.0%	0.0%	7.7%	92.3%	100.0%
Timing	[6]	0.0%	0.0%	35.0%	35.0%	65.0%	100.0%

Sources and Notes: [d] = [a] + [b] + [c].

[73] Apple and Samsung's collective share of tablets with GPS and smartphones is approximately 70% for each application.

Appendix 2. The Settlements with Leading Industry Manufacturers

On December 8, 2015, Ligado reached a settlement agreement with Deere & Company and only eight days later, on December 16, 2015, Ligado reached another settlement agreement with Garmin International, Inc. Collectively, I refer to these agreements as the "Compromise Settlements."[74] In partial fulfillment of these Compromise Settlements, Ligado filed a request to the FCC to modify its three ancillary terrestrial component authorizations on December 31, 2015 ("Ligado License Modifications").[75] One month later, on February 3, 2016, Ligado reached a settlement agreement with Trimble Navigation Limited ("Trimble Agreement").[76]

In the Compromise Settlements, Ligado agreed to forgo its terrestrial use of the 1545-1555 MHz band and to formalize this abandonment through a filing submitted to the FCC no later than December 31, 2015.[77] Ligado's obligation to abandon its terrestrial use of 1545-1555 MHz band was not contingent on the FCC granting Ligado any other relief. In addition, any future spectrum sharing agreements that Ligado may enter into may only be for earth-to-satellite communications in the 1545-1555 MHz band. The Trimble Agreement accepted Ligado's abandonment of the 1545-1555 MHz band for terrestrial use and required further

---

[74] See Letter from Gerard J. Waldron to Marlene H. Dortch, IB Docket No. 12-340, Dec. 8, 2015, accessed February 2, 2016, http://apps.fcc.gov/ecfs/document/view?id=60001352936 (Hereafter "Deere Agreement"); and Letter from Gerard J. Waldron to Marlene H. Dortch, IB Docket No. 12-340, Dec. 17, 2015, accessed February 2, 2016, http://apps.fcc.gov/ecfs/document/view?id=60001388035 (Hereafter "Garmin Agreement").

[75] The three ancillary terrestrial component authorizations included in the Ligado License Modification were: (i) modification of space station authorization with call sign S2358 and file number SATMOD2010111800239; (ii) modification of space station authorization with call sign AMSC-1 and file number SATMOD2014121200128; and (iii) modification of earth station with call sign E980179 and file number SESMFS2015060500325. See Letter from Gerard J. Waldron to Marlene H. Dortch, IB Docket No. 12-340 and IB Docket No. 11-109, December 31, 2015, accessed February 4, 2016, http://apps.fcc.gov/ecfs/document/view?id=60001396805.

[76] See Letter from Gerard J. Waldron to Marlene H. Dortch, IB Docket No. 12-340, Feb. 3, 2016, accessed February 4, 2016, http://apps.fcc.gov/ecfs/document/view?id=60001422644 (Hereafter "Trimble Agreement").

[77] As noted above, this condition was met through the Ligado License Modifications filed with the FCC on December 31, 2015.

acknowledgement by Ligado that it does not currently have, and will not seek, terrestrial authorization for any license in the 1537-1555 MHz band.[78]

As a part of the Compromise Settlements, Ligado agreed to specific out-of-band emissions ("OOBE") limits, frequency plans, specific handset and base station power levels. The OOBE limits and frequency plans are reflected in Ligado's new technical operating parameters.[79] The Compromise Settlements also specified base station EIRP power limits of 32 dBW in the 1526-1536 MHz band and the 1670-1700 MHz band[80] and handset EIRP power limits of 23 dBm in the 1627.5-1637.5 MHz band and the 1646.5-1656.5 MHz band.[81] The Ligado License Modifications incorporates all of these agreed-upon uplink and downlink power levels into its proposed "Technical Operating Parameters" diagram.[82] The Trimble Agreement then required that Ligado adopt the technical requirements outlined in Ligado License Modifications "through all necessary rule changes and license conditions."[83] In response to these agreed upon technical requirements, the Trimble Agreement calls for the removal of the consideration of deployment of Ligado's terrestrial network operating in spectrum with 1627.5 MHz or higher frequency from the pending Department of Transportation Adjacent Band Compatibility Assessment.[84]

In addition, under the Deere Agreement, Ligado is required to submit data to both Deere and the FCC demonstrating compliance for five years from the FCC's authorization of its terrestrial network. Under the Garmin Agreement, Ligado must submit this compliance data to Garmin for

---

78 Trimble Agreement.

79 *Comment Sought on Ligado's Modification Applications,* IB Docket Nos. 11-109 and 12-340, April 22, 2016, Public Notice (DA 16-442), p. 11.

80 The agreements go to 1700 MHz, but Ligado's proposal is only for 1670-1680 MHz operation. *Comment Sought on Ligado's Modification Applications*, IB Docket Nos. 11-109 and 12-340, April 22, 2016, Public Notice (DA 16-442), p. 11

81 The Garmin Agreement specified a linear ramp from -1 dBm to 23 dBm in the 1627.5-1632.5 MHz band and 23 dBm in the 1632.5-1637.5 MHz band. After five years, the limit would be 23 dBm in the entire 1627.5-1637.5 MHz band. See Garmin Agreement, Exhibit B.

82 *Comment Sought on Ligado's Modification Applications,* IB Docket Nos. 11-109 and 12-340, April 22, 2016, Public Notice (DA 16-442), p. 11.

83 Trimble Agreement.

84 Trimble Agreement.

a period of seven years.[85] Before deployment, Ligado is required to provide both Deere and Garmin with six months advance notice of activation of base stations in the 1526-1536 MHz band and/or the 1670-1700 MHz band. Ligado's advance notice must include an updated coverage map, at the county level, that shows Ligado's existing and anticipated coverage of its customers' terrestrial network and services.[86] The Trimble Agreement required Ligado to submit a similar coverage map to Trimble in order to help avoid potential interference issues from base station activations.[87] Finally, Ligado must provide Garmin with production quality handsets designed to transmit in the 1627.5-1637.5 MHz band and 1646.5-1656.5 MHz band for a period of seven years.[88]

Under the Compromise Settlements, Ligado has also agreed to withdraw and amend numerous petitions and applications that it has filed with the FCC. Ligado will withdraw its February 7, 2012 petition regarding receiver standard mandates for GNSS devices and its December 20, 2011 Petition for Declaratory Ruling concerning GNSS receiver spectrum rights.[89] As a part of withdrawing this petition, Ligado will not file a petition to the FCC, propose, or support any legislative measures to the FCC or Congress to impose receiver standards or a harms claim threshold for GNSS devices. The Compromise Agreements also specified that Ligado amend all of its petitions and applications to the FCC to conform to the operational and technical standards laid out in the Compromise Agreements, including:[90]

- Mobile Satellite Service Request to Modify the ATC Spectrum Rights Associated with MSAT (ET Docket No. 12-340)
- Petition for Rulemaking/Terrestrial Use of 1526-1536 MHz L-Band

---

[85] The Garmin Agreement also specifies that the test measurement and date be prepared by a neutral expert that is jointly decided upon by both Garmin and Ligado. See Garmin Agreement, p. 17.

[86] This advance notice is in effect for five years under the Deere Agreement and seven years under the Garmin Agreement. Ligado must update this coverage map every six months. See Deere Agreement, p. 4; Garmin Agreement, p. 18.

[87] Trimble Agreement, pp. 1-2.

[88] In addition to providing the handsets, Ligado must also provide any necessary technical support for testing the handsets. See Garmin Agreement, p. 18.

[89] Under the Deere Agreement, Ligado was also required to withdraw the December 20, 2011 filing if it reached a global settlement. See Deere Agreement, p. 5.

[90] Deere Agreement, p. 5; Garmin Agreement, pp. 19-20.

- Petition for Rulemaking/Allocation of 1675-1680 MHz for Terrestrial Use

In return for Ligado's concessions, Deere agreed to not object to Ligado deploying spectrum in the following bands: 1526-1536 MHz, 1627.5-1637.5 MHz, 1646.5-1656.5 MHz, and 1670-1700 MHz.[91] Similarly, Garmin agreed to not object to Ligado deploying spectrum in the 1627.5-1637.5 MHz, 1646.5-1656.5 MHz, and 1670-1700 MHz and, for devices that are not certified Garmin GNSS Aviation, in the 1526-1536 MHz band for a period of seven years.[92] Garmin and Ligado agreed to communicate on the aviation spectrum issue two to three times a year and Garmin agreed to not object to a request by Ligado to remove the Specified Network Frequencies from the Adjacent Band Compatibility Study.[93]

As noted above, many elements of the Trimble Agreement were similar to those included in the Compromise Settlements and the resulting Ligado License Modifications. In contrast to the Compromise Settlements, however, the Trimble Agreement acknowledged the continuing disagreement between Trimble and Ligado over the 1526-1536 MHz band:

> For the avoidance of doubt, (i) nothing in this agreement shall be deemed to limit either party's advocacy regarding any issue relating to terrestrial use of the 1526-1536 MHz band, other than the agreement of the Parties to support continued consideration of terrestrial use of the 1526-1536 MHz band in the currently pending DOT Adjacent Band Compatibility Assessment proceeding on a timetable and in accordance with the plans established by DOT, including, without

---

91 "Deere, acting as itself or through any third party, will not object to the deployment by New LightSquared of a network in the spectrum bands 1526-1536 MHz, 1627.5-1637.5 MHz, 1646.5-1656.5 MHz, and 1670-1700 MHz as long as such deployment is consistent with such filings." See Deere Agreement, p. 2.

92 Certified Garmin GNSS Aviation devices include all airborne navigation/position equipment that is installed in an aircraft. See Garmin Agreement, letter and pp. 4 and 22-23.

93 "In the event LightSquared requests that the DoT remove the Specified Network Frequencies from that certain Adjacent Band Compatibility Study (the "ABC Study"), Garmin, acting for itself or through any third party, will not object to such a request or provide Garmin GPS devices for the ABC Study for a period of seven (7) years from the Effective Date of this Settlement Agreement, provided and on the condition that (i) the proposed and actual use of the Specified Network Frequencies adheres to the Settlement Requirements; and (ii) Garmin may otherwise participate without restriction in the ABC Study." See Garmin Agreement, pp. 23-24.

limitation, the definition of harmful interference applicable to operations in the 1526-1536 MHz band.[94]

In return for the concessions made by Ligado in the Trimble Agreement, Trimble agreed to make its equipment "frequency agile" across the 1555-1559 MHz band. That is, Ligado will not require Trimble to move its operations outside the 1555-1559 MHz band but Trimble must be able to move operations across frequencies in this band within 120 days of notice of reassignment.[95]

---

[94] Trimble Agreement, pp. 3-4. In addition, Trimble and Ligado agreed to not object to the use of NASCTN laboratories testing interference issues in the 1526-1536 MHz band. See Trimble Agreement, p. 3.

[95] Trimble Agreement, p. 6.

Coleman Bazelon

Principal

Washington, D.C. +1.202.955.5050 Coleman.Bazelon@brattle.com

Dr. Coleman Bazelon is a Principal in the Washington, D.C. office of *The Brattle Group*. He is an expert in regulation, strategy and valuation in the wireless, wireline, and video sectors. He has consulted and testified on behalf of clients in numerous telecommunications matters, ranging from wireless license auctions, spectrum management, and competition policy, to patent infringement, business valuation, and broadband deployment.

Dr. Bazelon frequently advises regulatory and legislative bodies, including the U.S. Federal Communications Commission and the U.S. Congress. He also has expertise in the federal government's use of discount rates for policy and regulatory analysis, intellectual property valuation, economic impact analysis, and antitrust and damages analysis.

Throughout his career, Dr. Bazelon has had extensive experience with spectrum license auctions. He advises on and evaluates numerous auction designs and regularly serves as an auction advisor for bidders in spectrum license auctions.

Prior to joining *Brattle*, Dr. Bazelon was a Vice President with Analysis Group, an economic and strategy consulting firm. During that time, he expanded the firm's telecommunications practice area. He also served as a Principal Analyst in the Microeconomic and Financial Studies Division of the Congressional Budget Office where he researched reforms of radio spectrum management; estimated the budgetary and private sector impacts of spectrum-related legislative proposals; and advised on auction design and privatization issues for all research at the CBO.

SELECTED CONSULTING PROJECTS

Litigation

- Estimated value of a spectrum portfolio.
- Developed auction format for sale of private equity management firm.
- Estimated racial impact of voter ID law in Texas.
- Assessed Domestic Industry requirement in ITC 337 case involving mobile location patents.
- Evaluated damages in the applications market.
- Assessed allocation theories in an international bankruptcy.
- Evaluated damages from a programming contract termination.
- Evaluated damages from allegations of reputational harm in gaming equipment market.
- Evaluated damages from non-working wireless network equipment.
- Assessed Domestic Industry requirement in ITC 337 case involving wireless equipment patents.
- Assessed commercial viability of full text searching of books business model.

- Assessed Domestic Industry requirement in ITC 337 case involving portable storage device patents.
- Estimated value of satellite assets in bankruptcy.
- Estimated damages from denial of pole attachments.
- Provided written testimony evaluating the performance of a numbering resource administrator.
- Provided written testimony on the ability to estimate damages for a class of satellite phone users.
- Provided written testimony on the economic value of Rights-of-Ways in Massachusetts.
- Estimated damages for a broadcast tower permit revocation.
- Provided oral testimony on the proprietary nature of specific information contained in a statewide public safety network bid.
- Provided written testimony on economic value associated with items provided in a labor neutrality agreement.
- Estimated damages associated with USF and other telephone taxes paid by a calling card reseller.
- Assessed the damages associated with the infringement of patents related to VoIP technology and the likely impact of a permanent injunction.
- Estimated recoverable data costs for two pesticides.
- Estimated cost of delay in granting local cable franchise.
- Analyzed the economic underpinnings of an exclusivity clause of a mobile phone affiliation agreement.
- Assessed commonality issues of physicians for class certification of RICO action against a set of health insurance companies.
- Estimated “Loss of Use” damages for a severed fibre optic cable.
- Provided written testimony estimating the value of a surety bond in a contract dispute involving toll free phone numbers used in an enhanced service application.
- Assessed damages associated with infringement of patents used to provide Voice over Internet Protocol (VoIP).
- Assessed basis for guidance of a large telecommunications firm in a 10-b securities litigation.
- Valued digital television radio spectrum in St. Louis in the pre-litigation phase of a breach of contract dispute.
- Estimated damages in a breach of contract case involving the sale of a fibre optic network.
- Researched the basis for generally optimistic forecasts of broadband deployment in the later 1990s and early 2000s in an anti-trust litigation.
- Researched the basis for generally optimistic beliefs about the telecommunications sector .in the late 1990s in a 10-b securities litigation.
- Assessed the market for Competitive Local Exchange Carriers in an SEC fraud case.
- Assessed a bankruptcy sale proposal for a national tier 1 broadband backbone provider.
- Examined the business case asserted for a small wireless reseller in a breach of contract litigation.

- Assessed damages associated with infringement of patents used in DNA fingerprinting applications.
- Assessed changes in contributions to the Cable Royalty Fund on behalf of Sports Claimants in a Copyright Arbitration Royalty Panel (CARP) proceeding.
- Assessed the capital adequacy of the U.S. branch of a foreign bank.

Regulatory Proceedings

- Provided declaration on minority incentives in spectrum secondary market transactions.
- Evaluated proposed pole attachment rate.
- Analyzed cost[s] of USPS.
- Assessed impact on incentive auction of unlicensed operations in guard bands.
- Assessed market power in Canadian wireless market.
- Provided testimony in prison phone rate proceeding.
- Estimated economic impact of LNP on RLECs.
- Assessed relevance of U.S. UNE-L experience for New Zealand benchmarking proceeding.
- Authored analysis of harm from revoking LightSquared's ATC authorization.
- Estimated value of pairing Upper 700 MHz A Block with public safety.
- Estimated impact of increased regulatory uncertainty on spectrum value.
- Estimated value of government provision of GPS service to private industry.
- Coauthored analysis of feasibility of reallocating broadcast television through the use of incentive auctions.
- Analyzed impact on spectrum value of pairing AWS III spectrum.
- Coauthored analysis of the merits of licensed versus unlicensed allocation of the TV White Spaces.
- Estimated the value of TV White Spaces.
- Provided written testimony on the economic harm of using proprietary information in retention marketing.
- Provided written testimony on the economics of pole attachment rates.
- Estimated the value of the PCS H-Block spectrum band.
- Estimated the economic impact of ITC Exclusion Order on cell phone handsets.
- Authored several reports on the 700 MHz auction rules.
- Analyzed the relationship between the size of cable systems and the economics of the programming market.
- Presented analysis on pricing differentials in overlapping cable markets.
- Assessed proposed regulation of mobile phone roaming rates.
- Analyzed impact of local franchise requirements on competition in the video marketplace.
- Developed and assessed Indian spectrum management proposals.
- Analyzed economic ramifications of à la carte cable channel pricing on consumers and the cable and television programming industries.

- Examined the relative merits of licensed versus unlicensed radio spectrum and the effects of "underlay" licenses on existing commercial licensees.
- Examined federalism issues related to mobile telephony regulation.
- Examined and refuted arguments suggesting that the California Telecommunications Consumer Bill of Rights was an appropriate response to market failures.
- Assessed the impact on consumers of California's Telecommunications Consumer Bill of Rights proposal.
- Provided written testimony refuting analysis purporting to show a positive relationship between UNE-P and telecom network investment.
- Provided written testimony examining the effects of unbundling regulations on capital spending in the telecommunications sector.
- Estimated the adjustment to the TELRIC pricing formula to account for irreversible investment in the local telephone network.
- Examined the impact of irreversible investments in the local telephone network on the TELRIC pricing methodology.
- Assessed the degree of market overlap of two food service firms for purposes of merger review.
- Provided written testimony that assessed the validity of an analysis of the costs of a DTV tuner mandate.
- Provided written testimony of a forecast of toll free number demand for the toll free number administrator, SMS/800, in a rate case proceeding.

Other

- Evaluated impacts of Boston 2024's Olympic bid.
- Estimated value of licensed mobile broadband spectrum.
- Estimated future needs for licensed mobile broadband spectrum.
- Advised bidder in Canadian 700 MHz auction.
- Evaluated performance of TV stations when repacked in an Incentive Auction.
- Analyzed differences in U.S. and European wireless markets.
- Assessed business case and value of HF license holder.
- Analyzed likely auction outcomes for TV broadcaster participating in incentive auction.
- Assessed value of commercial mobile spectrum bands.
- Analyzed economic impacts of the commercial casino industry.
- Evaluated impact of digitization on copyright industries.
- Analyzed economic and employment effects of Dutch gas hub.
- Advised bidder in Indian 3G spectrum license auction.
- Estimated economic and employment effects of network neutrality regulation.
- Analyzed relative costs of wireless and wireline deployments in rural areas.
- Analyzed potential harms from Internet gambling.
- Estimated economic value of reallocating TV spectrum for wireless broadband.
- Estimated economic and employment effects of electric power transmission construction in support of new wind generation facilities.

- Estimated economic and employment effects of broadband stimulus grant applications.
- Estimated employment effects of an ATC-mobile satellite network deployment.
- Analyzed the impact of reducing international mobile phone roaming charges.
- Developed an auction platform for an electricity procurement auction.
- Analyzed the economic impacts of reduced mobile phone taxes in Africa and the Middle East.
- Evaluated the impact of reducing ethanol requirements on gasoline prices.
- Analyzed FRAND licensing requirements for intellectual property in the DTV standard.
- Advised bidder in Canadian AWS spectrum license auction.
- Advised bidder in FCC 700 MHz spectrum license auction.
- Evaluated a business plan for proposed dam removals.
- Assessed a business plan involving the WiMAX market.
- Estimated the value of a portfolio of spectrum licenses.
- Assessed the budgetary impacts of legislation to license TV white spaces.
- Analyzed the economics of the military's build versus buy decision for broadband satellite communications capacity.
- Advised bidder in FCC AWS spectrum license auction.
- Provided framework to estimate impact of the effect of designation of TV white spaces as unlicensed on 700 MHz auction receipts.
- Analyzed Universal Service Fund expenditures.
- Analyzed cable franchising requirements.
- Valued proposals to re-band the Upper 700 MHz Band of radio spectrum.
- Analyzed proposed accelerated digital television transition impacts on society and the federal budget.
- Coauthored a report on the value of a portfolio of patents used to provide Voice over Internet Protocol (VoIP).
- Coauthored a report to the U.S. Chamber of Commerce on the economic effects of telecommunications deregulation.
- Assessed the business cases for IRU swaps of a large international fibre optic network owner.
- Examined the effects of unbundling regulations on broadband penetration internationally.

TESTIMONY AND DECLARATIONS

"Amended Expert Report of Coleman Bazelon, Ph.D.," In the Matter of ACP Master, Ltd., Aurelius Capital Mater, Ltd., and Aurelius Opportunities Fund II, LLC, v. Sprint Corporation, Sprint Communications, Inc., Erik Prusch, John W. Stanton, William R. Blessing, Bruce A. Chatterley, Mufit Cinali, Jose A. Collazo, Hossein Eslambolchi, Dennis S. Hersch, Brian P. McAndrews, Kathleen H. Rae, Theodore H. Schell, Jennifer L. Vogel, Slade Gorton, Starburst I, Inc., and Softbank Corp., Court of Chancery, State of Delaware, C.A. No. 8508-VCL and ACP Master, Ltd., Aurelius Capital Mater, Ltd., and Aurelius Opportunities Fund II, LLC, v. Clearwire Corporation, Court of Chancery, State of Delaware, C.A. No. 9042-VCL, November 2, 2015.

"Rebuttal Report of Coleman Bazelon, Ph.D.," In the Matter of ACP Master, Ltd., Aurelius Capital Mater, Ltd., and Aurelius Opportunities Fund II, LLC, v. Sprint Corporation, Sprint Communications, Inc., Erik Prusch, John W. Stanton, William R. Blessing, Bruce A. Chatterley, Mufit Cinali, Jose A. Collazo, Hossein Eslambolchi, Dennis S. Hersch, Brian P. McAndrews, Kathleen H. Rae, Theodore H. Schell, Jennifer L. Vogel, Slade Gorton, Starburst I, Inc., and Softbank Corp., Court of Chancery, State of Delaware, C.A. No. 8508-VCL and ACP Master, Ltd., Aurelius Capital Mater, Ltd., and Aurelius Opportunities Fund II, LLC, v. Clearwire Corporation, Court of Chancery, State of Delaware, C.A. No. 9042-VCL, October 23, 2015.

"Expert Report of Coleman Bazelon, Ph.D.," In the Matter of ACP Master, Ltd., Aurelius Capital Mater, Ltd., and Aurelius Opportunities Fund II, LLC, v. Sprint Corporation, Sprint Communications, Inc., Erik Prusch, John W. Stanton, William R. Blessing, Bruce A. Chatterley, Mufit Cinali, Jose A. Collazo, Hossein Eslambolchi, Dennis S. Hersch, Brian P. McAndrews, Kathleen H. Rae, Theodore H. Schell, Jennifer L. Vogel, Slade Gorton, Starburst I, Inc., and Softbank Corp., Court of Chancery, State of Delaware, C.A. No. 8508-VCL and ACP Master, Ltd., Aurelius Capital Mater, Ltd., and Aurelius Opportunities Fund II, LLC, v. Clearwire Corporation, Court of Chancery, State of Delaware, C.A. No. 9042-VCL, September 25, 2015.

"Expert Rebuttal Report on Domestic Industry of Coleman Bazelon, Ph.D.," In the Matter regarding Certain Non-Volatile Memory Chips and Products Containing the Same, Investigation No. 337-TA-916, December 15, 2014.

"Expert Report on Remedy and Bonding of Coleman Bazelon, Ph.D.," In the Matter regarding Certain Non-Volatile Memory Chips and Products Containing the Same, Investigation No. 337-TA-916, December 15, 2014.

"Expert Report on Public Interest of Coleman Bazelon, Ph.D.," In the Matter regarding Certain Non-Volatile Memory Chips and Products Containing the Same, Investigation No. 337-TA-916, November 24, 2014.

"Expert Report of Coleman Bazelon, Ph.D.," In the Matter regarding Wynnchurch Capital Ltd., In the Court of Chancery of the State of Delaware, C.A. No. 10077-VCL, November 7, 2014.

"Third Amended Reply Report of Coleman Bazelon, Ph.D.," On Behalf of Plaintiff-Intervenors Texas League of Young Voters Education Fund and Imani Clark, United States District Court for the Southern District of Texas Corpus Christi Division, Civ. No. 2:13-cv-00263, September 22, 2014.

"Reply Report of Coleman Bazelon, Ph.D.," On Behalf of Plaintiff-Intervenors Texas League of Young Voters Education Fund and Imani Clark, United States District Court for the Southern District of Texas Corpus Christi Division, Civ. No. 2:13-cv-193 (NGR), August 15, 2014.

"Expert Report of Coleman Bazelon, Ph.D.," In the Matter of the Texas League of Young Voters Education Fund and Imani Clark v. State of Texas, Nandita Berry, in her official capacity as Texas Secretary of State; and Steve McGraw, in his official capacity as Director of the Texas Department of Public Safety, United States District Court for the Southern District of Texas Corpus Christi Division, Civ. No. 2:13-cv-00263, June 27, 2014.

"Rebuttal Expert Report of Coleman Bazelon, Ph.D.," In the Matter of the Companies' Creditors Arrangement Act, R.S.C. 1985, c. C-36, As Amended, and in the Matter of a Plan of Compromise or Arrangement of Nortel Networks Corporation, Nortel Networks Limited, Nortel Networks Global Corporation, Nortel Networks International Corporation and Nortel Networks Technology Corporation United States Bankruptcy Court for the District of Delaware, Case No. 09-10138 (KG), February 28, 2014.

"Supplemental Expert Report of Coleman Bazelon, Ph.D.," In the Matter of Sky Angel U.S., LLC, against Discovery Communications, LLC, Animal Planet, LLC, United States District Court for the District of Maryland, Case No. 8:13-cv-00031-DKC, January 31, 2014.

"Expert Report of Coleman Bazelon, Ph.D.," In the Matter of the Companies' Creditors Arrangement Act, R.S.C. 1985, c. C-36, As Amended, and in the Matter of a Plan of Compromise or Arrangement of Nortel Networks Corporation, Nortel Networks Limited, Nortel Networks Global Corporation, Nortel Networks International Corporation and Nortel Networks Technology Corporation United States Bankruptcy Court for the District of Delaware, Case No. 09-10138 (KG), January 24, 2014.

"Expert Report of Coleman Bazelon, Ph.D.," In the Matter of Sky Angel U.S., LLC, against Discovery Communications, LLC, Animal Planet, LLC, United States District Court for the District of Maryland, Case No. 8:13-cv-00031-DKC, December 6, 2013.

"Expert Report of Coleman Bazelon, Ph.D. and Armando Levy, Ph.D," In the Matter of LT Game International Ltd., against Shuffle Master, Inc., United States District Court for the District of Nevada, Case No. 2:12-cv-01216-JAD-GWF, October 4, 2013.

"Expert Report of Coleman Bazelon, Ph.D.," In the Matter of Certain Electronic Devices, Including Wireless Communications Devices, Tablet Computers, Media Players, and Televisions, and Components Thereof, United States International Trade Commission, Investigation No. 337-TA-862 (Judge Shaw), July 5, 2013.

"Declaration of Coleman Bazelon" In the Matter of PTA-FLA, Inc, Daredevil, Inc., NTCH-WEST TENN., Inc., NTCH-WA, Inc., and Eric Steinmann against ZTE Corporation, and ZTE USA, Inc. Florida Arbitration, Case No.: 50-494-T-00665-11, February 26, 2013.

"Rebuttal Testimony of Coleman Bazelon," In re: Petition for Suspension or Modification of Application of the Requirements of 47 U.S.C. § 251(b) and (c), pursuant to 47 U.S.C. § 251(f)(2) regarding Time Warner Cable Information Services (Maine) LLC's Request, State of Maine Public Utilities Commission, Docket No. 2012-198, Docket No. 2012-218, Docket No. 2012-219, Docket No. 2012-220, Docket No. 2012-221, October 12, 2012.

"Testimony of Coleman Bazelon, Ph.D.," In re: Petition for Suspension or Modification of Application of the Requirements of 47 U.S.C. § 251(b) and (c), pursuant to 47 U.S.C. § 251(f)(2) regarding Time Warner Cable Information Services (Maine) LLC's Request, State of Maine Public Utilities Commission, Docket No. 2012-198, Docket No. 2012-218, Docket No. 2012-219, Docket No. 2012-220, Docket No. 2012-221, August 20, 2012.

"Expert Report of Dr. Coleman Bazelon," *Salsgiver Communications, Inc., Salsgiver Telecom, Inc., and Salsgiver Inc. v. Consolidated Communications Holdings, Inc., North Pittsburgh Systems, Inc., and North Pittsburgh Telephone Company, Inc.,* Court of Common Pleas, Allegheny County, Pennsylvania, Civil Division, No. GD 08-7616, May 10, 2012.

"Effect of the Proposed Merger on Service Quality, Consumer Services, Employment, and California's Economy," Panelist on behalf of AT&T before the Public Utilities Commission of the State of California, Order Instituting Investigation on the Commissioner's Own Motion into the Planned Purchase and Acquisition by AT&T Inc. of T-Mobile USA, Inc., and Its Effect on California Ratepayers and the California Economy. Case No. I.11-06-009, July 22, 2011.

"Oral Testimony of Coleman Bazelon, The Brattle Group, Inc. before the U.S. House of Representatives, Committee on Energy and Commerce Subcommittee on Communication and Technology," April 12, 2011. (spectrum)

"Testimony of Coleman Bazelon, Principal, *The Brattle Group*, before the U.S. House of Representatives, Committee on Energy and Commerce, Subcommittee on Communications, Technology, and the Internet," June 17, 2010 (spectrum valuation).

"Supplemental Expert Report of Coleman Bazelon," *Gemalto PTE LTD and Gemplus S.A. v. Telecommunications Industry Association*, United States District Court for the Eastern District of Virginia, Alexandria Division, Case 1:08-cv-00776-LMB-TRJ, December 16, 2008.

"Expert Report of Coleman Bazelon," *Gemalto PTE LTD and Gemplus S.A. v. Telecommunications Industry Association*, United States District Court for the Eastern District of Virginia, Alexandria Division, Case 1:08-cv-00776-LMB-TRJ, November 6, 2008.

"Prefiled Rebuttal Testimony of Coleman D. Bazelon," In re: Complaint and Request for Emergency Relief Against Verizon Florida LLC for anticompetitive behavior in violation of Sections 364.01(4), 364.3381, and 364.10, F.S., and for failure to facilitate transfer of customers' numbers to Bright House Networks Information Services (Florida) LLC, and its affiliate, Bright House Networks, LLC, Florida Public Service Commission, Docket No. 070691-TP, July 25, 2008.

"Prefiled Direct Testimony of Coleman D. Bazelon," In re: Complaint and Request for Emergency Relief Against Verizon Florida LLC for anticompetitive behavior in violation of Sections 364.01(4), 364.3381, and 364.10, F.S., and for failure to facilitate transfer of customers' numbers to Bright House Networks Information Services (Florida) LLC, and its affiliate, Bright House Networks, LLC, Florida Public Service Commission, Docket No. 070691-TP, May 30, 2008.

"Declaration of Coleman Bazelon in Support of Plaintiffs' Motion for Class Certification," *Kenneth Stickrath, et al v. Globalstar, Inc.*, United States District Court for the Northern District of California, San Francisco Division, Case No. 07-CV-01941 TEH, April 25, 2008.

"Testimony of Coleman Bazelon, Principal, *The Brattle Group*, before the U.S. House of Representatives, Committee on Energy and Commerce, Subcommittee on Telecommunications and the Internet," April 15, 2008 (reviewing the 700 MHz auction).

"Concerning the Meaning of 'Fair and Reasonable Compensation' in Section 253(c) of the Telecommunications Act of 1996 and the Comparability of the Rights-of-Way Fees Paid by Level 3 in Massachusetts and Elsewhere," *The Massachusetts Turnpike Authority v. Level 3 Communications, LLC, et al.,* The United States District Court for the District of Massachusetts, Civ. Act. No. 06-11816, December 17, 2007.

"Concerning the Effects of the Fixed Rent Charged for Access to the Massachusetts Turnpike," *The Massachusetts Turnpike Authority v. Level 3 Communications, LLC, et al.,* The United States District Court for the District of Massachusetts, Civ. Act. No. 06-11816, November 12, 2007.

"Affidavit of Dr. Coleman Bazelon," *Gulfside Casino Partnership v. Mississippi Riverboat Council, et al.*, United States District Court for the Southern District of Mississippi, Southern Division, Cause No. 1:07-CV-110-LG-JMR, May 4, 2007.

"Rebuttal Report of Dr. Coleman Bazelon," *Level 3 Communications, LLC, v. City of St. Louis, Missouri*, United States District Court for the Eastern District of Missouri, Eastern Division, Consolidated Case No. 4:04-CV-871 CAS, June 17, 2005.

"Affidavit of Dr. Coleman Bazelon," *Informed Communications Systems, Inc. v. Intelogistics Corp., d/b/a Prosodie Interactive*, United States District Court, Southern District of Florida, Miami Division, Case No.: 04-61245 CIV Huck/Turnoff (October 12, 2004).

EXPERT DESIGNATIONS

- *Touch America, Inc. v. Qwest Communications International, Inc.*
  - Designated as an expert in Arbitration (June 2003)
- *Informed Communications Systems, Inc. v. Intelogistics Corp., d/b/a Prosodie Interactive*, United States District Court, Southern District of Florida, Miami Division, Case No.: 04-61245 CIV Huck/Turnoff
  - Filed affidavit (October 12, 2004)
- *Level 3 Communications, LLC v. City of St. Louis, Missouri*, United States District Court for the Eastern District of Missouri, Eastern Division, Consolidated Case No. 4:04-CV-871 CAS
  - Filed Rebuttal Report (June 17, 2005)
  - Deposition (July 14, 2005)
- Cable Merger before the FTC
  - Presented analysis to FTC staff (March 20, 2007)
- *Gulfside Casino Partnership v. Mississippi Riverboat Council, et al.*, United States District Court for the Southern District of Mississippi, Southern Division, Cause No. 1:07-CV-110-LG-JMR
  - Filed affidavit (May 4, 2007)
- *Motorola, Inc. v. State of Mississippi Department of Information Technology Services and M/ACom, Inc.*, Chancery Court of Hinds County, Mississippi, Cause No. G2006-2179 S/2
  - Testified (May 23, 2007)
- *American Towers, Inc. v. Jackson & Campbell, P.C., et al.*, DC Superior Court, No. 003277-06
  - Deposition (March 19, 2009)
  - Filed Affidavit (May 22, 2009)

- *The Massachusetts Turnpike Authority v. Level 3 Communications, LLC, et al.,* The United States District Court for the District of Massachusetts, Civ. Act. No. 06-11816
    - Filed Expert Report (November 12, 2007)
    - Filed Rebuttal Report (December 17, 2007)
    - Deposition (January 21, 2008)
- *Kenneth Stickrath, et al v. Globalstar, Inc.,* United States District Court for the Northern District of California, San Francisco Division, Case No. 07-CV-01941 THE
    - Filed Declaration (April 25, 2008)
    - Deposition (June 11, 2008)
- In re: Complaint and request for emergency relief against Verizon Florida LLC for anticompetitive behavior in violation of Sections 364.01(4), 364.3381, and 364.10, F.S., and for failure to facilitate transfer of customers' numbers to Bright House Networks Information Services (Florida) LLC, and its affiliate, Bright House Networks, LLC, Florida Public Service Commission, Docket No. 070691-TP
    - Filed Direct Testimony (May 30, 2008)
    - Filed Rebuttal Testimony (July 25, 2008)
    - Deposition (August 13, 2008)
- *Gemalto PTE LTD and Gemplus S.A. v. Telecommunications Industry Association,* United States District Court for the Eastern District of Virginia, Alexandria Division, Case 1:08-cv-00776- LMB-TRJ
    - Filed Expert Report (November 6, 2008)
    - Deposition (December 2, 2008)
    - Filed Supplemental Expert Report (December 16, 2008)
- *Salsgiver Communications, Inc., Salsgiver Telecom, Inc., and Salsgiver Inc. v. Consolidated Communications Holdings, Inc., North Pittsburgh Systems, Inc., and North Pittsburgh Telephone Company, Inc.*, Court of Common Pleas, Allegheny County, Pennsylvania, Civil Division, No. GD 08-7616
    - Filed Damages Analysis (February 27, 2009)
    - Deposition (April 3, 2012)
    - Filed Expert Report (May 10, 2012)
    - Testified (May 6, 2015; May 12, 2015)
- *Certain Products Containing Interactive Program Guide and Parental Control Technology* United States International Trade Commission, Investigation No. 337-TA-820

  - Designated as an expert (June 8, 2012)
- In re: Petition for Suspension or Modification of Application of the Requirements of 47 U.S.C. § 251(b) and (c), pursuant to 47 U.S.C. § 251(f)(2) regarding Time Warner Cable Information Services (Maine) LLC's Request, State of Maine Public Utilities Commission, Docket No. 2012-198, Docket No. 2012-218, Docket No. 2012-219, Docket No. 2012-220, Docket No. 2012-221
  - Filed Direct Testimony (August 20, 2012)
  - Filed Rebuttal Testimony (October 12, 2012)
  - Testified (October 23, 2012)
- In the matter of PTA-FLA, Inc , Daredevil, Inc., NTCH-WEST TENN., Inc., NTCH-WA, Inc., and Eric Steinmann against ZTE Corporation, and ZTE USA, Inc. Florida Arbitration, Case No.: 50-494-T-00665-11
  - Filed Expert Report (February 26, 2013)
  - Deposed (March 15, 2013)
  - Testified (August 30, 2013)
- *Certain Electronic Devices, Including Wireless Communications Devices, Tablet Computers, Media Players, and Televisions, and Components Thereof*, United States International Trade Commission, Investigation No. 337-TA-862 (Judge Shaw)
  - Filed Rebuttal Testimony (July 5, 2013)
- In the matter of LT Game International Ltd., against Shuffle Master, Inc., United States District Court for the District of Nevada, Case No. 2:12-cv-01216-JAD-GWF
  - Filed Expert Report (October 4, 2013)
  - Deposed (November 12, 2013)
- In the Matter of Sky Angel U.S., LLC, against Discovery Communications, LLC, Animal Planet, LLC, United States District Court for the District of Maryland, Case No. 8:13-cv-00031-DKC
  - Filed Expert Report (December 6, 2013)
  - Filed Supplemental Report (January 31, 2014)
  - Deposed (February 14, 2014)
- In the Matter of the Companies' Creditors Arrangement Act, R.S.C. 1985, c. C-36, As Amended, and in the Matter of a Plan of Compromise or Arrangement of Nortel Networks Corporation, Nortel Networks Limited, Nortel Networks Global Corporation,

Nortel Networks International Corporation and Nortel Networks Technology Corporation United States Bankruptcy Court for the District of Delaware, Case No. 09-10138 (KG)

- Filed Expert Report (January 24, 2014)
- Filed Rebuttal Expert Report (February 28, 2014)
- Deposed (April 3, 2014; May 30, 2014)
- Testified (June 2, 2014; June 5, 2014)

- *State of Texas v. Eric H. Holder, Jr., in his Official Capacity as Attorney General of the United States*, United States District Court for the District of Columbia, Case No. 1:12-CV-00128
  - Filed Expert Report (June 27, 2014)
  - Filed Reply Report (August 15, 2014)
  - Deposed (August 20, 2014)
  - Testified (September 9, 2014)
  - Filed Third Amended Reply Report (September 22, 2014)
- Certain Wireless Devices, Including Mobile Phones And Tablets II, United States International Trade Commission, Investigation No. 337-TA-905 (Judge Pender)
- Wynnchurch Capital Ltd., In the Court of Chancery of the State of Delaware, C.A. No. 10077-VCL
  - Filed Expert Report (November 7, 2014)
  - Deposed (November 17, 2014)
- In the Matter of: Certain Non-Volatile Memory Chips and Products Containing the Same, United States International Trade Commission, Washington, D.C., Investigation No. 337 TA-916
  - Filed Expert Report on Public Interest (November 24, 2014)
  - Filed Expert Rebuttal Report on Domestic Industry (December 15, 2014)
  - Filed Expert Report on Remedy and Bonding (December 15, 2014)
  - Deposed (January 9, 2015)

- In the Matter of: Certain Non-Volatile Memory Chips and Products Containing the Same, United States International Trade Commission, Washington, D.C., Investigation No. 337 TA-922

- In the Matter of: Certain Footwear Products, United States International Trade Commission, Washington, D.C., Investigation No.337-TA-936

- In the Matter of ACP Master, Ltd., Aurelius Capital Mater, Ltd., and Aurelius Opportunities Fund II, LLC, v. Sprint Corporation, Sprint Communications, Inc., Erik Prusch, John W. Stanton, William R. Blessing, Bruce A. Chatterley, Mufit Cinali, Jose A. Collazo, Hossein Eslambolchi, Dennis S. Hersch, Brian P. McAndrews, Kathleen H. Rae, Theodore H. Schell, Jennifer L. Vogel, Slade Gorton, Starburst I, Inc., and Softbank Corp., Court of Chancery, State of Delaware, C.A. No. 8508-VCL and ACP Master, Ltd., Aurelius Capital Mater, Ltd., and Aurelius Opportunities Fund II, LLC, v. Clearwire Corporation, Court of Chancery, State of Delaware, C.A. No. 9042-VCL
    - Filed Expert Report (September 25, 2015)
    - Filed Rebuttal Report (October 23, 2015)
    - Filed Amended Expert Report (November 2, 2015)
    - Deposed (November 10, 2015)

PUBLICATIONS

Articles and Book Chapters

Coleman Bazelon and Giulia McHenry, "Spectrum Value," *Telecommunications Policy*, Volume 37, issue 9, October 2013, pp. 737-747.

John Jarosz, Robin Heider, Coleman Bazelon, Christine Bieri and Peter Hess, "Patent Auctions: How Far Have We Come?" *les Nouvelles*, March 2010, pp. 11-30.

"Too Many Goals: Problems with the 700 MHz Auction," *Information Economics and Policy*, June 2009, pp. 115-127.

"Licensed or Unlicensed: The Economic Considerations in Incremental Spectrum Allocations," *IEEE Communications Magazine*, March 2009, pp. 110-116.

Michael H. Rothkopf and Coleman Bazelon, "Interlicense Competition: Spectrum Deregulation Without Confiscation or Giveaways," OBTAINING THE BEST FROM REGULATION AND COMPETITION, Michael A. Crew and Menahem Spiegel, eds., Kluwer Academic Publishers (2005), pp. 135-159.

"Next Generation Frequency Coordinator," *Telecommunications Policy* 27 (2003), pp. 517-525.

Coleman Bazelon and Kent Smetters, "Discounting in the Long Term," *Loyola of Los Angeles Law Review*, Vol. 35, Issue 1, November 2002.

Coleman Bazelon and Kent Smetters, "Discounting Inside the Washington DC Beltway," *Journal of Economic Perspectives*, Fall 1999.

"The Movement of Markets," *Wesleyan Economic Journal*, Spring 1986.

"Is the Psychogenic Theory of History Scientific?" *Journal of Psychohistory*, Fall 1985.

White Papers, Reports, Studies, and Reviews

Coleman Bazelon and Lucrezio Figurelli, "The Economic Costs and Benefits of a Federal mandate that All Light Vehicles Employ 5.9 GHz DSRC Technology," National Cable & Telecommunications Association, May 2, 2016.

David Sunding, Martha Rogers, and Coleman Bazelon, " The Farmer and the Data: How Wireless Technology is Transforming Water Use in Agriculture," CTIA Wireless Foundation, April 22, 2016.

Coleman Bazelon, Nicol E. Turner-Lee, Olga Ukhaneva, and DeVan Hankerson, "A Lifeline to High-Speed Internet Access: An Economic Analysis of Administrative Costs and the Impact on Consumers," Multicultural Media, Telecom And Internet Council, March 2016.

Coleman Bazelon, Pallavi Seth, Steven Hercovici, Mark Berkman, Allen Sanderson, Brad Humphreys, Joseph Floyd, and Michael Abasciano, "Analysis of the Boston 2024 Proposed Summer Olympic Plans," Prepared for Commonwealth of Massachusetts Office of the Governor, President of the Senate, and Speaker of the House, August 17, 2015.

Coleman Bazelon and Giulia McHenry, "Substantial Licensed Spectrum Deficit (2015-2019): Updating the FCC's Mobile Data Demand Projections," Prepared for CTIA – The Wireless Association, June 23, 2015.

Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the U.S. Economy," Prepared for CTIA – The Wireless Association, May 11, 2015.

Kevin Hearle, Giulia McHenry, James Reitzes, Jeremy Verlinda and Coleman Bazelon, "Vertical Foreclosure in Canadian Wholesale Services Markets," Supplemental Filing, Prepared for the Canadian Competition Bureau, August 18, 2014.

Kevin Hearle, Giulia McHenry, James Reitzes, Jeremy Verlinda and Coleman Bazelon, "Canadian Wireless Market Performance and the Potential Effect of an Additional Nationwide Carrier," Prepared for the Canadian Competition Bureau, May 12, 2014.

Coleman Bazelon and Giulia McHenry, "Spectrum Sharing: Taxonomy and Economics," Office of Science and Technology Policy, filed comment March 18, 2014.

Coleman Bazelon and Giulia McHenry, "Spectrum Sharing: Taxonomy and Economics," sponsored by Verizon, February 6, 2014.

Coleman Bazelon and Giulia McHenry, “The Economics of Spectrum Sharing,” Telecommunications Policy Research Conference, 2013.

Coleman Bazelon and Giulia McHenry, “Violating Your Privacy: An Economic Perspective,” Telecommunications Policy Research Conference, September 24, 2013.

Coleman Bazelon and Giulia McHenry, “The Economics of Spectrum Sharing,” *Global Media and Communications Quarterly*, Hogan Lovells, Autumn 2013, pp. 47-51.

Robert Shapiro, Douglas Holtz-Eakin and Coleman Bazelon, “The Economic Implications of Restricting Spectrum Purchases in the Incentive Auctions,” Georgetown University Center for Business & Public Policy, April 2013.

Lisa Cameron and Coleman Bazelon, “The Impact of Digitization on Business Models in Copyright-Driven Industries: A Review of the Economic Issues,” National Research Council (NRC) Committee on the Impact of Copyright Policy on Innovation in the Digital Era, February 26, 2013.

Robert A. Rogowsky, Pallavi Seth, and Coleman D. Bazelon, "An Economic View of ITC 337 Cases and the Public Interest," *Law360*, November 21, 2012.

Coleman Bazelon and Giulia McHenry, “Spectrum Value,” Telecommunications Policy Research Conference, 2012.

Robert A. Rogowsky, Pallavi Seth, and Coleman D. Bazelon, "An Economic View Of The ITC's Domestic Industry," *Law360*, June 18, 2012.

Coleman Bazelon and Greg Duncan, “The Status of UNE-L in the United States,” Prepared for the Commerce Commission of New Zealand, April 12, 2012.

“Implications of Regulatory Inefficiency for Innovative Wireless Investments,” Sponsored by LightSquared, March 15, 2012.

Coleman Bazelon, Kevin Neels and Pallavi Seth, “Beyond the Casino Floor: Economic Impacts of the Commercial Casino Industry,” sponsored by the American Gaming Association, 2012.

Coleman Bazelon, Charles Jackson and Giulia McHenry, “An Engineering and Economic Analysis of the Prospects of Reallocating Radio Spectrum from the Broadcast Band through the Use of Voluntary Incentive Auctions,” Telecommunications Policy Research Conference, 2011.

“Cost of Regulatory Risk for Wireless Spectrum Values,” sponsored by LightSquared, August 23, 2011.

“Expected Receipts from Proposed Spectrum Auctions,” sponsored by the Wireless Broadband Coalition, July 28, 2011.

"GPS Interference: Implicit Subsidy to the GPS Industry and Cost to LightSquared of Accommodation," sponsored by LightSquared, June 22, 2011.

Lisa Cameron and Coleman Bazelon, "The Impact of Digitization on Business Models in Copyright-Driven Industries: A Review of the Economic Issues," National Research Council (NRC) Committee on the Impact of Copyright Policy on Innovation in the Digital Era, June 7, 2011.

"The Economic Basis of Spectrum Value: Pairing AWS-3 with the 1755 MHz Band is More Valuable than Pairing it with Frequencies from the 1690 MHz Band," sponsored by T-Mobile and CTIA, April 11, 2011.

"Economists Letter to Obama Regarding Incentive Auctions," April 6, 2011.

"The Indian 3G and BWA Auctions," Telecommunications Policy Research Conference, 2010.

"Economic Impact of the Dutch Gas Hub Strategy on the Netherlands," by Dan Harris, Coleman D. Bazelon, Brad Humphreys, and Penelope Dickson, *Netherlands Ministry of Economic Affairs, Agriculture and Innovation*, September 2010.

"The Employment and Economic Impacts of Network Neutrality Regulation: An Empirical Analysis," sponsored by Mobile Future, 2010.

"The Benefits of Wireless Broadband for Rural Deployments," sponsored by Qualcomm, Inc, 2010.

"Comments of 71 Concerned Economists – Using Procurement Auctions to Allocate Broadband Stimulus Grants," Submitted to the National Telecommunications Information Agency (NTIA) and Rural Utilities Service (RUS), April 13, 2009.

Malcolm K. Sparrow, Coleman Bazelon and Charles Jackson, "Can Internet Gambling Be Effectively Regulated? Managing the Risks," sponsored by Wired Safety, 2009.

"The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations," sponsored by Consumer Electronics Association, 2009.

Coleman Bazelon and William Zarakas, "Measuring Concentration in Radio Spectrum License Holdings," Telecommunications Policy Research Conference, 2009.

"Licensed or Unlicensed: The Economic Considerations in Incremental Spectrum Allocations," in *New Frontiers in Dynamic Spectrum Access Networks, 2008*, DySPAN 2008.

"Overreaching: The Policy Failures of the 700 MHz Auction," Telecommunications Policy Research Conference, 2008.

"Cream Skimming," Telecommunications Policy Research Conference, 2007.

Thomas W. Hazlett and Coleman Bazelon, "Market Allocation for Radio Spectrum," prepared for the International Telecommunications Union Workshop on Market Mechanisms for Spectrum Management, Geneva, Switzerland, January, 2007.

"Licensed or Unlicensed: The Economics of Incremental Spectrum Allocations," Telecommunications Policy Research Conference, 2006.

"Analysis of an Accelerated Digital Television Transition," sponsored by Intel Corporation, 2005.

Thomas W. Hazlett and Coleman Bazelon, "Regulated Unbundling of Telecommunications Networks: A Stepping Stone to Facilities-Based Competition?" Telecommunications Policy Research Conference, 2005.

Thomas W. Hazlett, Coleman Bazelon, John Rutledge, and Deborah Allen Hewitt, Sending the Right Signals: Promoting Competition Through Telecommunications Reform: A Report to the U.S. Chamber of Commerce, September 22, 2004.

Thomas W. Hazlett, Arthur M. Havenner, and Coleman Bazelon, "Regulation and Investment in Local Telecommunications Networks," Working Paper, January 2004.

Michael H. Rothkopf and Coleman Bazelon, "Interlicense Competition: Spectrum Deregulation Without Confiscation or Giveaways," New America Foundation, Spectrum Series Working Paper #8, August, 2003.

"Review of Discounting and Intergenerational Equity," by Paul Portney and John Weyant, Resources for the Future (1999), in the Society of Government Economists Newsletter, Volume 34, No. 10, November 2002.

"Completing the Transition to Digital Television," Congressional Budget Office, September 1999.*

"Two Approaches for Increasing Spectrum Fees," Congressional Budget Office, November 1998 (Coauthored with David Moore*).

"Where Do We Go From Here? The FCC Auctions and the Future of Radio Spectrum Management," Congressional Budget Office, April 1997 (Coauthored with Perry Beider and David Moore*).

* CBO publications do not cite authors' names.

Federal Communications Commission Filings

Erratum to the October 15, 2015 Ex Parte notice, "Rates for Interstate Inmate Calling Services", WC Docket No. 12-375, October 16, 2015.

"Memorandum in Response to Securus Filing," Ex Parte Written Presentation, Rates for Interstate Inmate Calling Services, WC Docket No. 12-375, August 28, 2015.

"Memorandum to provide an analysis of the Cost Study submissions by the ICS providers," Ex Parte Written Presentation, Rates for Interstate Inmate Calling Services, WC Docket No. 12-375, August 14, 2015.

"Unlicensed Operations in the 600 MHz Band: Fatally Flawed Twice Over," with Charles Jackson and Dorothy Robyn, ET Docket No. 14-165, GN Docket No. 12-268, February 25, 2015.

"Staying on Track: Realizing the Benefits from the FCC's Incentive Auction without Delay," with Giulia McHenry, Comments of LocusPoint Networks, LLC, Attachment A, AU Docket No. 14-252, GN Docket No. 12-268, February 20, 2015.

"Reply Declaration of Coleman Bazelon," Reply Comments of Martha Wright, Et. Al., The D.C. Prisoners' Legal Services Project, Inc., and Citizens United for Rehabilitation of Errants, WC Docket No. 12-375, January 27, 2015.

"Reply Declaration of Coleman Bazelon," Comments of Martha Wright, et. al., Exhibit A, WC Docket No. 12-375, April 22, 2013 (prison payphone rates).

"Declaration of Coleman Bazelon," Comments of Martha Wright, et. al., Exhibit C, WC Docket No. 12-375, March 25, 2013 (prison payphone rates).

"Declaration of Coleman Bazelon," Verizon Telephone Companies and Verizon Services Corp., v. Madison Square Garden, L.P., and Cablevision Systems Corp., FCC Filling, File No. CSR-8185-P, October 22, 2010 (program access complaint).

"Unlicensed Use of the TV White Spaces: Wasteful and Harmful," FCC Filling, with Charles L. Jackson and Dorothy Robyn, *Ex Parte* Comments, ET Docket No. 04-186, ET Docket No. 02-380, August 20, 2008 (benefits of licensed over unlicensed allocation of the TV White Spaces).

"Comments of Charles L. Jackson, Dorothy Robyn and Coleman Bazelon," Comments, WC Docket No. 06-150, PS Docket No. 06-229, June 20, 2008 (value of TV White Spaces).

"Comments of Coleman Bazelon," Comments, WC Docket No. 06-150, PS Docket No. 06-229, WT Docket No. 96-86, June 20, 2008 (700 MHz D Block).

"Declaration of Coleman Bazelon," Reply Comments, WC Docket No. 07-245, April 22, 2008 (economics of pole attachment rates).

"Why the Exclusive Use of Large Licenses in the Upper or Lower 700 MHz Bands Would Reduce the Efficiency of the 700 MHz Auction," Comments, WT Docket No. 06-150, April 20, 2007.

"Principles for Choosing 700 MHz Block License Sizes," *Ex Parte* Comments, WT Docket No. 06-150, March 6, 2007.

"The Economics of License Sizes in the FCC's 700 MHz Band Auction," *Ex Parte* Comments, WT Docket No. 06-150, January 2007.

"Declaration of Thomas W. Hazlett, Ph.D., Prof. Arthur M. Havenner, and Coleman Bazelon, Ph.D.," Comments, WC Docket No. 03-173, December 16, 2003. (Wireline investment, UNE-P)

"Declaration of Thomas W. Hazlett, Ph.D., Arthur M. Havenner, Ph.D., and Coleman Bazelon, Ph.D.," Comments, WC Docket No. 03-157, September 2, 2003. (Wireline investment, UNE-P)

"Spectrum Deregulation Without Confiscation or Giveaways," with Michael Rothkopf, Comment, ET Docket No. 02-135, January 9, 2003.

Thomas W. Hazlett, Coleman Bazelon and Arthur Havenner, "Forecast of Toll Free Number Demand: 2002-2004," Attachment A, SMS/800 Transmittal No. 22, F.C.C. Tariff No. 1, November 15, 2002.

"Comments of Coleman D. Bazelon and T. Christopher Borek Relating to Arthur D. Little, Inc.'s Assessment of the Impact of DTV on the Cost of Consumer Television Receivers," *Ex Parte* Comments MM Docket 00-39, August 1, 2002.

"Use Administrative Law Judges to Adjudicate Interference Disputes Between Licensees," Comment, ET Docket No. 02-135, July 8, 2002.

SEMINARS AND PRESENTATIONS

Government Seizures of Property, Ferrum College Forum, Ferrum, Virginia, March 14, 2016.

"The $100 Billion Question: Who Gets The Spectrum?" NAB Content and Communications World, New York, New York, November 11, 2015.

Spectrum versus Infrastructure: Complimentary Assets, Cowen and Company Communications Infrastructure Summit, Boulder, Colorado, August 12, 2015.

Moving Towards General Purpose Spectrum, Aspen Institute Roundtable on Spectrum Policy (AIRS), Queenstown, Maryland, October 22 – 24, 2014.

Winnik International Telecoms & Internet Forum: The Internet of Things, Washington, D.C., October 22, 2014.

Spectrum Sharing: How Much Can It Contribute? Technology Policy Institute Aspen Forum, Aspen, Colorado, August 18, 2014.

Internet Privacy, Civil Liberties, National Security, Law, and Economics: In Search of a Coherent Policy Path Forward, Ferrum College Forum, Ferrum, Virginia, March 19, 2014.

S*pectrum Auctions Are Back: What you need to know,* Bloomberg BNA Webinar, February 19, 2014.

Violating Your Privacy: An Economic Perspective, 41st Annual Telecommunications Policy Research Conference (TPRC), Arlington, VA, September 28, 2013.

Other Recent and Planned Spectrum Auctions: What They Portend for the Future: Economic Perspectives on the Auctions, Law Seminars International, Washington, D.C., July 22, 2013.

Spectrum Auction Policy: Potential Outcomes for Economic Growth and Public Safety, Georgetown University McDonough School of Business, Rayburn House Office Building, Washington, D.C., May 14, 2013.

Markets in Wireless Spectrum, Towards Dynamic Markets in Electric Power, Water, and Wireless Spectrum Seminar, University of Colorado Law School, Boulder, CO, April 23, 2013.

Ethics and Intellectual Entrepreneurship, Annual College of Social Studies Spring Banquet key note speaker, Wesleyan University, Middletown, CT, April 17, 2013.

The Underwood Memorial Lecture and Hoggendorn lecture for the Economic Department, Wesleyan University, Middletown, CT, April 18, 2013.

Food-Water- Energy The Right Balance, Ferrum College Forum panel, Ferrum, Virginia, March 12, 2013.

FCC Incentive Auction Rules: Estimating Clearing Prices and Policy Impacts, SNL Knowledge Center Webinar, February 27, 2013.

Reverse Auction Design: Dynamic or Sealed, Algorithmic Issues, Market Power, Reserves, Reference Prices, Conference on the FCC Incentive Auction, Stanford Institute for Economic Policy Research, Stanford, CA, February 26, 2013.

Mobile Impact on Economic Growth and Job Creation, Consumer Electronics Show, LIT Program Innovation Policy Summit, Las Vegas, NV, January 8, 2013.

Incentive Auctions: What Broadcasters Need to Know, Crossfire Media Webinar, December 19, 2012.

Spectrum Value, 40th Annual Telecommunications Policy Research Conference (TPRC), Arlington, VA, September 22, 2012.

FCBA Seminar: Getting from Here to There: The Road Ahead for Spectrum Auctions, Washington, DC, June 6, 2012.

Incentive Auctions, 39th Annual Telecommunications Policy Research Conference (TPRC), Arlington, VA, September 24, 2011.

Competition in the Wireless Environment: How to Get More Handsets or More Networks, Broadband Breakfast Club, Washington, DC, February 15, 2011.

Introducing TV White Spaces, Spectrum Bridge webinar, October 28, 2010.

The Indian 3G and BWA Auctions, 38th Annual Telecommunications Policy Research Conference (TPRC), Arlington, VA, October 2, 2010.

How Smart Public Policies Can Drive the Mobile Broadband Transformation, Information Technology and Innovation Foundation's The Emerging Mobile Broadband Economy and its New Business Models, Washington, DC, September 14, 2010.

Community Broadband-A Blessing or Curse?, K&L Gates LLP Municipal Broadband Webcast, July 29, 2010.

Towards A Sustainable Spectrum Policy: Rethinking Federal Spectrum, Public Knowledge, Washington, DC, June 3, 2010.

Unraveling Net Neutrality: Should the FCC Regulate Broadband, Independence Institute, Denver, CO, May 26, 2010.

CQ-Roll Call Policy Breakfast on the Future of Wireless Broadband, Washington, DC, May 20, 2010.

Congressional Staff Briefings on "The Need for Additional Spectrum for Wireless Broadband: The Economic Benefit and Costs of Reallocations," Washington, DC, December 8, 2009.

The Progress and Freedom Foundation's "Let's Make a Deal: Broadcasters, Mobile Broadband, and a Market in Spectrum," Washington, DC, December 1, 2009.

FCBA's Intellectual Property Practice Committee Brown Bag Lunch, Washington, DC, November 30, 2009.

FCC Broadband Spectrum Workshop, Washington, DC, September 17, 2009.

Measuring Concentration in Radio Spectrum License Holdings, 37th Annual Telecommunications Policy Research Conference (TPRC), Arlington, VA, September 26, 2009.

Broadband Stimulus Plan, 2009 FLATOA-FCBA Conference, Tampa, FL, June 26, 2009.

Leveraging the Broadband Stimulus and Licensed Spectrum, Webinar, April 29, 2009.

Keynote Address, Enterprise Wireless08, Scottsdale, AZ, November 6, 2008.

Licensed or Unlicensed: The Economic Considerations in Incremental Spectrum Allocations, DySPAN, Chicago, IL, October 16, 2008.

Overreaching: The Policy Failures of the 700 MHz Auction, 36th Annual Telecommunications Policy Research Conference (TPRC), Arlington, VA, September 27, 2008.

Cream Skimming, 35th Annual Telecommunications Policy Research Conference (TPRC), Arlington, VA, September 29, 2007.

Auction Revenues are not the Only Revenues that Should Drive Spectrum Policy, Law Seminars International: Spectrum Management, Washington, DC, September 17, 2007.

Market Allocation for Radio Spectrum, International Telecommunications Union Workshop on Market Mechanisms for Spectrum Management, Geneva, Switzerland, January 2007.

Licensed vs. Unlicensed Spectrum: A New Economic Model for Determining the Trade-offs, 34th Annual Telecommunications Policy Research Conference (TPRC), Arlington, VA, September 30, 2006.

Decoding the Future of IP-TV, Northern California Chapter of the Federal Communications Bar Association, San Francisco, February 2006.

Accelerating the Digital Television Transition, COMPTEL Executive Business & Policy Summit, Washington, DC, December 2005.

Regulated Unbundling of Telecommunications Networks: A Stepping Stone to Facilities Based Competition? Telecommunications Policy Research Conference, Arlington, VA, September 2005.

Sending the Right Signals: Promoting Competition Through Telecommunications Reform: A Report to the U.S. Chamber of Commerce, presentation of report to the US Chamber of Commerce, October 6, 2004.

Telecommunications Reform, presentation to the U.S. Chamber of Commerce's Technology Policy Committee, April 29, 2004.

Interlicense Competition, Telecommunications Policy Research Conference, Arlington, VA, September 2003.

Marketing & Legal Strategies: Hope, Hype & Crash Landings, WCAI 2003, Washington, DC, July 10, 2003.

Spectrum Policy Task Force Interference Recommendations, Manhattan Institute Conference, Washington, DC, February 13, 2002.

FCC License Auctions, Society of Government Economists Conference, Washington, DC, November 22, 2002.

Spectrum Management Panel, CTIA Wireless 2002, Orlando, FL, March 18, 2002.

A Note on Correlation, ASSA Annual Meetings, Atlanta, GA, January 6, 2002.

Regulatory Forbearance, Powerline Communications Conference, Washington, DC, December 13, 2001.
Spectrum License Valuations, CTIA Wireless Agenda 2001, Dallas, TX, May 2001.

Old Spectrum in the New Economy, with David Moore, invited paper, Society of Government Economists Conference "The New 'Economy': What Has Changed and Challenges for Economic Policy," Washington, DC, November 2000.

Discounting Inside the Washington DC Beltway, Energy Information Agency Seminar Series, Washington, DC, March 2000.

Discounting Inside the Washington DC Beltway, Congressional Budget Office Seminar Series, Washington, DC, November 1999.

Completing the Transition to Digital Television, Telecommunications Policy Research Conference, Arlington, VA, September 1999.

Digital Television Transition, Congressional Budget Office Seminar Series, Washington, DC, April 1999.

The Budgetary Treatment of Asset Sales, briefing for the staff of the Senate Budget Committee, Washington, DC, February 1997.

The Value Added from Multilateral Bargaining Theory for Applied Research, with Greg Adams, Selected Paper, AAEA Annual Meeting, Baltimore, MD, August 1992.

The Importance of Political Markets in Formulating Economic Policy Recommendations, Selected Paper, AAEA Annual Meeting, Manhattan, KS, August 1991.

L.D.C. Debt and Policy Linkages in the Determination of World Commodity Prices, with Gordon Rausser, Selected Paper, AAEA Annual Meeting, Vancouver, B.C., Canada, August 1990.

REVIEWER

- American Journal of Agricultural Economics (1989 – 1994)
- Congressional Budget Office Reports
- Telecommunications Policy
- Telecommunications Policy Research Conference Program Committee (2011-2013)
- George Mason University

PROFESSIONAL AFFILIATIONS

- American Bar Association

- American Economic Association
- Federal Communications Bar Association
- National Research Council - Committee on a Survey of the Active Scientific Use of the Radio Spectrum

EDUCATION

Dr. Bazelon received his Ph.D. and M.S. in Agricultural and Resource Economics from the University of California at Berkeley. He also holds a Diploma in Economics from the London School of Economics and Political Science and a B.A. from Wesleyan University.

May 2, 2016