

GPS Interference:
Implicit Subsidy to the GPS Industry and
Cost to LightSquared of Accommodation

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June 22, 2011

Acknowledgments: This research was sponsored by LightSquared. I would like to thank Abhinab Basnyat, David Klumpp, and Giulia McHenry for their invaluable help in preparing this paper. All errors remain mine.

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I. EXECUTIVE SUMMARY

Radio spectrum is a scarce resource and care must be taken to assure it is put to its highest valued uses. When the benefits of deploying spectrum for a new use—such as terrestrial wireless broadband—are greater than the added costs to other users, then the spectrum should be used for this new, valuable use.

By making intensive use of otherwise underused spectrum, LightSquared's proposed 4G Long Term Evolution (LTE) network is introducing wireless broadband services worth approximately \$12 billion in value to the economy and potentially 10 times that amount or \$120 billion in benefits to consumers. Derailing LightSquared's deployment of LTE in the L-Band, therefore, would cause significant economic harm. Additionally, LightSquared's plans for an LTE network are an integral part of both providing critical public safety services and narrowing the looming wireless broadband capacity crisis in the U.S.

By offering services and applications that utilize the GPS satellite network and government spectrum, commercial GPS device manufacturers enjoy a substantial implicit subsidy from the U.S. government. I estimate that the total value of this subsidy is worth \$18 billion to U.S. commercial GPS users.

While LightSquared has ensured that its transmissions are not intruding into GPS spectrum, LightSquared's transmissions interfere with GPS devices that do not adequately filter spectrum beyond the GPS allocated spectrum bands. As a result, GPS receivers are effectively utilizing L-Band spectrum below the GPS spectrum allocation. Given time, the GPS industry can remedy their interference problem by installing more precise filters into GPS receivers used in the U.S. Given that relatively few devices in the U.S. will have to be retrofitted and adding filters to new devices is rather inexpensive (\$0.30 per device by one estimate), this cost is quite limited in comparison to the value to the economy of utilizing L-Band spectrum for wireless broadband.

II. INTRODUCTION

Radio spectrum is a scarce resource and care must be taken to assure it is put to its highest valued uses.¹ Deploying an Ancillary Terrestrial Component (ATC) to a satellite network is one such opportunity to assure spectrum is put to its highest valued use. Typically, the terrestrial component of satellite spectrum goes unused. However, if the benefits of deploying ATC are greater than the added costs to other users, then the spectrum should be used for this new, valuable use.

¹ See the Principle of Spectrum Reallocation as discussed in "Oral Testimony of Coleman Bazelon," *The Brattle Group, Inc.* U.S. House of Representatives, Committee on Energy and Commerce Subcommittee on Communication and Technology. April 12, 2011. Found at: http://democrats.energycommerce.house.gov/sites/default/files/image_uploads/Testimony_04.12.11_Bazelon.pdf (last visited June 20, 2011).

LightSquared's proposed LTE network will create significant value. By making intensive use of otherwise underused spectrum, LightSquared is introducing wireless broadband services into the marketplace that create approximately \$12 billion in value to the economy and potentially 10 times that amount or \$120 billion in benefits to consumers.² Derailing LightSquared's deployment of LTE in the L-Band would cause significant economic harm. Consequently, in evaluating the trade-offs associated with resolving any potential interference issues with GPS, the larger context of the benefits of LightSquared's deployment of ATC spectrum should not be lost.

GPS satellite transmission was originally allocated to the 1559 MHz – 1610 MHz band for military purposes primarily, but was increasingly focused on commercial uses by 2000. Since then, the federal government has made substantial efforts to encourage commercial users,³ and a number of commercial GPS devices and applications have proliferated in the market.⁴ These commercial GPS users include a range of applications across a variety of industries. Some examples include 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.⁵ These commercial applications have become so important that since 2005 all new satellites have been equipped with L2C signals for civilian users in order to encourage the commercial uses of GPS.⁶

² Based on the updated value of unencumbered AWS wireless broadband spectrum is worth approximately \$1.00 per MHz-Pop. (More specifically the value as of April 7, 2011 was \$1.05/MHz-pop. See Table 2 in Bazelon, Coleman. "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," *The Brattle Group*. April 11, 2011. Found at: http://www.brattle.com/_documents/UploadLibrary/Upload938.pdf (last visited June 20, 2011). (Herein "The Economic Basis of Spectrum Value"). This implies that the economic value for LightSquared's 40 MHz of nationwide L band spectrum dedicated to terrestrial broadband is approximately \$12 billion. Furthermore, wireless broadband spectrum is typically thought to generate consumer surplus equal to at least 10 times the original value of the original spectrum. See Rosston, Gregory L. "The long and winding road: the FCC paves the path with good intentions," *Telecommunications Policy*. Vol. 27, 2003, pp. 501 – 515. This suggests a consumer surplus of at least \$120 billion.

³ A 2004 presentation by the Office of Space Commercialization at the U.S. Department of Commerce illustrates that the government has made efforts to expand the number of commercial users to take advantage of the GPS satellite network. According to the 1996 GPS Policy, "Our goals are to: ...Encourage private sector investment in and use of U.S. GPS technologies and services." See Kim, Jason Y. "Commercial Uses of GPS," *Office of Space Commercialization, U.S. Department of Commerce*. September 13, 2004. Found at: <http://www.pnt.gov/public/1997-2004/2004-09-brazil/> (last visited June 20, 2011). (Herein "Commercial Uses of GPS, DOC 2004").

⁴ See James, Randy. "A Brief History of GPS," *Time*. May 26, 2009. Found at: <http://www.time.com/time/nation/article/0,8599,1900862,00.html> (last visited June 20, 2011). (Herein "Time, May 26, 2009").

⁵ See Commercial Uses of GPS, DOC 2004. See also GPS Applications webpage at <http://www.gps.gov/applications/> (last visited June 20, 2011).

⁶ For more information about L2C, see "Second Civil Signal: L2C," webpage at GPS.gov. Found at: <http://www.gps.gov/systems/gps/modernization/civilsignals/#L2C> (last visited June 20, 2011).

All told, the U.S. government has spent an estimated \$35 billion on the GPS satellite network and continues to make substantial investments in its modernization.⁷ For 2012 alone, the combined federal budget request is \$1.67 billion for U.S. GPS programs. This includes \$1.42 billion requested by Department of Defense (DOD)/U.S. Air Force, \$189.3 million for Department of Transportation (DOT)/Federal Aviation Administration, \$7.6 million for DOT/Research and Innovative Technology Administration, and \$9.7 million for Department of Homeland Security/U.S. Coast Guard (USCG).⁸

By offering services and applications that utilize the GPS satellite network, commercial GPS device manufacturers enjoy a substantial implicit subsidy from the U.S. government. Unlike most commercial users of radio frequencies, commercial GPS users enjoy the privilege of using the GPS satellite network at no cost. In contrast, once they acquire FCC spectrum licenses, commercial wireless broadband providers must invest billions of dollars to build and maintain a network of transmission sites or satellites in order to provide services to customers. If the GPS satellite network was privately held or not provided to users for free, GPS service providers would either have to pay for some sort of GPS service license, or build and maintain such a satellite navigation system privately. Below, I estimate the total value of this subsidy to be worth \$18 billion to U.S. commercial GPS users.

LightSquared and its predecessors have been providing Mobile Satellite Service (MSS) since 1996 and now plan to offer 4G mobile broadband services on the ATC. Its customers include both commercial and public users—most notably public safety and emergency response operators. As the FCC has noted, the applications for LightSquared’s services include land-based (*i.e.*, voice, wireless broadband, and asset tracking); maritime navigation; and a variety of critical, life-saving government services used by Federal Emergency Management Agency, USCG, and local fire and police departments.⁹ Recently, LightSquared has invested \$1.1 billion to build and launch the first of two next-generation satellites that will be part of its integrated combined satellite and 4G terrestrial LTE network.¹⁰

See also list of commercial attendees and discussants at the “Next-Generation GPS for Enhanced Business Productivity: Because Time is Money, and Location is Everything!” *U.S. Chamber of Commerce Seminar Program*. January 25, 2006. Found at:

<http://www.space.commerce.gov/library/workshops/2006-01-25/> (last visited June 21, 2011).

⁷ For estimates of the U.S. total expenditure, see “GPS Threatened with Widespread Interference,” White Paper. *Save Our GPS Website*. Found at:

http://www.saveourgps.org/GPS_Threatened_with_Widespread_Interference.aspx (last visited June 20, 2011).

⁸ For information on 2012 funding requests see “Fiscal Year 2012 Program Funding” webpage. *Space-Based Positioning Navigation & Timing National Executive Committee* website. Found at: <http://www.pnt.gov/policy/legislation/funding/2012.shtml> (last visited June 20, 2011).

⁹ “Order and Authorization in the Matter of LightSquared Subsidiary LLC Request for Modification of its Authority for an Ancillary Terrestrial Component,” *FCC*. Docket DA 11-133. January 26, 2011, p. 2. (Herein “Order and Authorization for LightSquared, January 26, 2011”).

¹⁰ “LightSquared Announces the Successful Launch of Next-Generation Satellite,” *LightSquared Press Release*. November 15, 2010. Found at: <http://www.lightsquared.com/press-room/press-releases/lightsquared-announces-the-successful-launch-of-next-generation-satellite/> (last visited

Going forward, LightSquared is poised to build-out the terrestrial component of this integrated, nationwide network, which is an integral part of both providing critical public safety services and narrowing the looming wireless broadband capacity crisis.¹¹ As the FCC also noted, the benefits of LightSquared include enhancing services to public safety and homeland security by offering mobile wireless broadband services, providing additional broadband capacity, enhancing competition among more wireless providers, and increasing innovations for new consumer devices.¹² LightSquared's terrestrial build-out of the L-Band and integrated services are critical to meeting the National Broadband Plan (NBP) goals for wireless broadband by 2015.¹³

In order to build such a terrestrial network, LightSquared planned to devote 40 MHz of L-Band spectrum to terrestrial use. LightSquared has acquired rights to 46 MHz of L-Band frequencies between 1626.5 MHz – 1660.5 MHz (uplink) and 1525 MHz – 1559 MHz (downlink). The remaining 6 MHz of its L-Band will be devoted to MSS.¹⁴ In addition to covering 100% of the U.S. population with satellite services, LightSquared has committed to build-out 4G terrestrial LTE based service to at least 36% of the population (100 million people) by the end of 2012 and at least 92% of the U.S. population (260 million people) by 2015.¹⁵

Initial tests of LightSquared's terrestrial base stations, however, have shown that these transmissions can cause interference issues for GPS receivers. The GPS interference problem is not caused by LightSquared signals intruding into GPS spectrum, but rather because many of the existing GPS devices do not adequately filter spectrum beyond the GPS allocated spectrum bands.¹⁶ LightSquared has ensured that their spectrum will not interfere in the GPS frequencies developing base station filters that effectively cut off all signals above 1559 MHz. GPS users acknowledge there is no problem with out-of-band

June 20, 2011). For information on LightSquared's satellites, Skyterra 1 and Skyterra 2, see "Skyterra: Next Generation Mobile Communications Platform," *Boeing Factsheet*. Found at: <http://www.boeing.com/defense-space/space/bss/factsheets/geomobile/msv/msv.html> (last visited June 20, 2011).

¹¹ For a discussion of the looming wireless broadband demand crisis see "Mobile Broadband: the Benefits of Additional Spectrum," *FCC Staff Technical Working Paper*. October 2010, p. 17. (Herein "The Benefits of Additional Spectrum, FCC October 2010").

¹² See Order and Authorization for LightSquared, January 26, 2011.

¹³ One NBP goal is to release 300 MHz of spectrum for wireless broadband by 2015. The L-Band is a critical component of this 300 MHz. See "Chapter 5: Spectrum," *Connecting America: the National Broadband Plan*. FCC. Exhibit 5-E, p. 84. Further, according to a related FCC report, this NBP goal is critical to meeting demand for wireless spectrum in 5 years. See The Benefits of Additional Spectrum, FCC October 2010.

¹⁴ See Farrar, Tim. "Profile of LightSquared," *TMF Associates*. October 29, 2010, pp. 5 and 7. (Herein "Profile of LightSquared, October 29, 2010").

¹⁵ See Order and Authorization for LightSquared, January 26, 2011, p. 4.

¹⁶ See Farrar, Tim. "Fixing the GPS interference problems," *TMF Associates MSS blog*. April 6, 2011. Found at: <http://tmfassociates.com/blog/2011/04/06/fixing-the-gps-interference-problems/> (last visited June 20, 2011). (Herein "TMF Associates, April 6, 2011").

emissions.¹⁷ Rather, the interference experienced by existing GPS receivers is caused by GPS receivers that do not currently filter frequencies below the bottom of the GPS allocated spectrum at 1559 MHz. Put another way, it is not the case that LightSquared transmissions are interfering with GPS spectrum, but rather GPS receivers are effectively utilizing L-Band spectrum below the GPS spectrum allocation.

Traditionally GPS receivers have been able to function with filters that do not adequately filter all radio frequencies neighboring the spectrum allocated to GPS. Until LightSquared's terrestrial build-out, the neighborhood around the GPS spectrum allocation was used in a way that did not interfere with GPS, including for MSS satellites.¹⁸ Although technology exists to adequately fix the interference problem from LightSquared's ATC signals discussed above,¹⁹ there has previously been no need for GPS devices to incur the expense of using filters that can block radiowaves in the adjacent L Band.

Given time, there is a solution for the GPS industry to remedy their interference problem by installing more precise filters into GPS receivers used in the U.S. This will likely involve integrating new filters into all new devices used in the U.S., as well as retrofitting more permanent devices that are not likely to be replaced over the next few years. For many GPS devices, including various types of consumer navigation devices, the average lifespan is short enough that most of the existing receivers will be replaced in the coming years—many before the LightSquared network is fully deployed. These devices will be replaced by new devices with better filters at an estimated cost of about \$0.30 per device.²⁰ Many of the GPS receivers that have a longer expected lifespan, including those used for aviation and marine navigation, will have to be retrofitted. Given that relatively few devices in the U.S. will have to be retrofitted and adding filters to new

¹⁷ See TMF Associates, April 6, 2011 and John Deere Presentation to FCC, attached to Electronic Filing regarding Notice of Ex Parte Presentation in LightSquared Subsidiary LLC Request for Modification of its Authority for an Ancillary Terrestrial Component. IBFS File No. SAT-MOD-20101118-00239. March 21, 2011. (Herein "John Deere Presentation to FCC").

¹⁸ Adams, Charlotte. "The GPS crisis: how serious is it?" *Avionics Intelligence*. May 4, 2011. Found at: http://www.militaryaerospace.com/index/display/avi-article-display/6339849046/articles/avionics-intelligence/features-and-analysis/2011/5/the-gps_crisis__how.html (last visited June 20, 2011).

For information on the MSS L-Band allocation see Divis, Dee Ann. "Spectrum Allocation Frequency Decisions Pending," *GPS World*. March 2000. Found at: http://findarticles.com/p/articles/mi_m0BPW/is_3_11/ai_n27557507/ (last visited June 20, 2011).

¹⁹ See, for example, Qualcomm's comments on their discussion with the FCC regarding their plans to remedy similar problems in their cellular devices. Comments filed by Qualcomm at the FCC regarding "Ex Parte Notification – IB File No. SAT-MOD-20101118-00239." January 21, 2011. Searchable at: http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/related_filing.hts?f_key=-216679&f_number=SATMOD2010111800239 (last visited June 20, 2011). (Herein "Qualcomm Comments to FCC, January 21, 2011").

²⁰ See TMF Associates, April 6, 2011; and Arthur, Charles. "US wireless network could drown out GPS, experts warn," *Guardian*. April 6, 2011. Found at: <http://www.guardian.co.uk/technology/2011/apr/06/us-wireless-network-lightsquared-gps> (last visited June 19, 2011).

devices is rather inexpensive, the cost to GPS of remedying this interference is quite limited when compared to the cost of LightSquared's proposed accommodation or the subsidy enjoyed by the GPS industry.

This report proceeds as follows. Section III discusses the implicit subsidy U.S. commercial GPS users enjoy by using the GPS satellite network at no cost. Section IV discusses the benefits enjoyed by the GPS industry by not adequately filtering devices up until now, and the costs of preparing GPS devices for when LightSquared does begin utilizing its entire L-Band spectrum holdings.

III. IMPLICIT SUBSIDY TO U.S. COMMERCIAL GPS INDUSTRY

By using the GPS satellite network free of charge, commercial GPS device manufacturers enjoy substantial benefits at no cost. In order to offer the same geo-location services they do today without the U.S. Government's GPS satellite network, these commercial users would have to rely on some equivalent system. This is a cost that the commercial GPS users do not face, because the Federal Government allocates valuable spectrum for GPS transmissions and invests in GPS satellite infrastructure and operations, but does not charge commercial users for the use of the spectrum or these GPS services. The implicit subsidy to commercial GPS users is then the opportunity cost they would face in order to offer the same services to their customers if they could not use the U.S. Government's GPS satellite system or the spectrum for transmission for free.

Since there are no commercial alternatives presently available, commercial users would have to build a satellite system capable of offering commercial geo-location services. The Federal government has spent an estimated \$35 billion on the current GPS network since it began GPS operations in the mid-1970s.²¹ This network was designed and is operated for more than just commercial users—for example, by the military, both domestically and internationally—so a network with the equivalent functionality for commercial users would not necessarily need to replicate the current GPS network. For instance, the U.S. Government's GPS network uses 24 satellites, but has 31 functioning satellites and 3-4 decommissioned satellites that could likely be restored if necessary. This is sufficient to ensure the DOD standard that 95.7% of the time a satellite-position will be occupied by a functional satellite.²² A commercial system, would certainly require some backup service, but might not find the same level of reliability required by the DOD economical to provide. Though many GPS devices are designed to work worldwide, for the purposes of this analysis, I assume that a commercial GPS system would only need to cover the continental U.S.²³ An alternative, commercially focused

²¹ See footnotes 7 and 8 for a discussion of funding estimates. See also *Time*, May 26, 2009.

²² See "Global Positioning System Standard Positioning Service Performance Standard," *Department of Defense*. 4th Edition. September 2008, p. 30. Found at: <http://www.pnt.gov/public/docs/2008/spgps2008.pdf> (last visited June 20, 2011). (Herein "GPS Service Performance Standard, 2008").

²³ Certainly there are some U.S. commercial GPS services abroad—for example tracking cargo—but these uses are limited and it is likely not worth the incremental value of building a global satellite

GPS system would likely require fewer satellites than the current GPS network provided by the U.S. military. As discussed below, in order to build a GPS satellite system sufficient for U.S. commercial purposes only, a reasonable estimate is that it would require at least 18 functioning satellites.

For a GPS receiver to provide an accurate estimate of its position on the Earth's surface, it must be able to receive signals from 4 separate GPS satellites.²⁴ These signals together are sufficient to identify the receiver's time, latitude, longitude, and altitude. A GPS satellite system that provides service anywhere in the United States must be able to offer a user full view of at least 4 satellites at any given time and location. Satellites rotate around the earth in orbital planes that must pass over the equator. Placing at least 4 satellites in an orbit ensures that, if you are within range of an orbit from a given position on the earth's surface, you will be in view of a satellite in that orbit.

For a configuration similar to the existing U.S. NavStar-GPS satellite constellation, ensuring complete coverage in the continental U.S. would require at least 18 satellites, including 16 in operation and 2 spares in orbit.²⁵ The existing U.S. NavStar-GPS satellite constellation is comprised of 6 orbital planes, each of which requires a minimum complement of 4 satellites²⁶ in medium-altitude orbit.²⁷ This guarantees the user a view of at least 4 satellites from almost any point on the Earth's surface. For a similar configuration, a continental U.S.-only GPS system could continue to have at least 4 satellites in an orbital plane, but would likely require fewer than 6 orbital planes to ensure U.S. coverage. At a minimum, such a system would require at least 4 orbital planes, because a user would need see at least 4 satellites at any time and position on the earth's surface in the continental U.S. (a user cannot be guaranteed a view of more than 1

network. To be conservative, therefore, this analysis assumes these users pursue alternative technologies, and a more limited U.S. only network is sufficient. This estimate is even further discounted by not including Alaska or Hawaii.

²⁴ See "NAVSTAR GPS User Equipment Introduction," *United States Coast Guard Navigation Center*. September 1996, p. 13. Found at:

<http://www.navcen.uscg.gov/pubs/gps/gpsuser/gpsuser.pdf> (last visited June 20, 2011).

²⁵ In addition to the possibility of satellite failure, GPS satellites must regularly be temporarily taken off line in order to make adjustments to their orbits. A constellation, therefore, should be designed to work with 1 satellite offline for maneuvering even when another satellite has failed. This suggests a minimum of 2 spare satellites. This is consistent with the 2008 Department of Defense Performance Standards, which consider the failure of up to 2 satellites in their calculations of GPS receiver accuracy. See GPS Service Performance Standard, 2008, p. B-14.

²⁶ For official U.S. Government Information about the Global Positioning System and related topics see "Space Segment," webpage at GPS.gov. Found at: <http://www.gps.gov/systems/gps/space/> (last visited June 20, 2011). (Herein "Space Segment, GPS.gov").

²⁷ Some systems deploy a handful of geo-stationary high-orbit satellites, such as the Chinese COMPASS GPS network. However, a full network of geo-stationary satellites could not be designed, as all of these satellites must occupy a single orbital plane. See "Astrophysicist Q&A," *NASA Goddard Space Flight Center*. April 1997. Found at: http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/970408d.html (last visited June 20, 2011).

satellite per orbital plane).²⁸ These 4 orbital planes with 4 satellites each would therefore require at least 16 total satellites functioning at any given time. Further, a U.S. commercial system would need a minimum of at least 2 spare satellites in orbit in addition to the baseline 16 in order to make the system reasonably robust to satellite failure.²⁹

Table 1 shows that the estimated present value of expenditure for building and operating a commercial GPS satellite system for 30 years is \$18 billion. Building and operating a satellite system requires an initial capital expenditure, ongoing operating expenses and an additional capital expenditure in 12 to 15 years to replace aging satellites.³⁰ The value of satellite spectrum licenses that might be needed by a private system in order to transmit signals is an additional cost. The initial capital expenditure includes research and development, satellite builds, launch costs and launch insurance, and building ground systems and related infrastructure to operate the satellites.

The estimated cost of building the original 18 satellites is \$3.6 billion, with an additional \$1 billion for R&D and \$1.1 billion for launch and insurance costs. In 2008 Lockheed Martin won the contract to develop and build the next generation constellation of GPS III satellites. The value of the contract included an initial \$1.5 billion for R&D and two satellites, as well as the option to procure an additional 10 satellites for another \$2.1 billion.³¹ Based on this contract, the cost of an individual satellite is a little over \$200 million, with an initial R&D cost of just over \$1 billion. In addition to the initial 18 satellites, the replacement cost of each satellite in 15 years will be an additional \$200 million per satellite. In 2010, Arianespace of France was contracted to launch all 14 EU Galileo satellites for €397 million.³² Based on the current exchange rate, this translates

²⁸ This can be seen by comparing the distribution of the 4 satellites in an orbital plane with the “footprint,” or visible range on the earth’s surface, of each satellite See GPS Service Performance Standard, 2008, p. A-4.

²⁹ There are alternative constellation configurations that could also operate with 18 – 20 satellites. For instance, GLONASS uses more than 4 satellites per orbital plane to reduce the number of planes from 6 to 3. The system can provide global positioning for Russia exclusively with a total of 18 satellites. See Polischuk, G. M.; *et al.* “The Global Satellite Navigation System GLONASS: Development and Usage in the 21st Century, Russian Aerospace Agency. 2002. Found at: <http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA484380> (last visited June 20, 2011). See also Novosti, Ria. “Russia to Set World Record with 39 Space Launches in 2009,” 2008. Found at: <http://en.rian.ru/russia/20081229/119210306.html> (last visited June 20, 2011).

³⁰ Life expectancy for the GPS IIF satellites initially launched in 2010 is 12 years, while the life expectancy of the new IIIA satellites in development is 15 years. See Space Segment, GPS.gov.

³¹ See Gibbons, Glen. “Lockheed Martin Wins GPS IIIA Contract,” *Inside GNSS*. May 16, 2008. Found at: <http://www.insidegnss.com/node/681> (last visited June 20, 2011). (Herein “*Inside GNSS*, May 16, 2008”). See also Hedgepeth, Dana and Zachary A. Goldfarb. “Lockheed Wins GPS Satellite Contract,” *Washington Post*. May 16, 2008. Found at: http://www.washingtonpost.com/wp-dyn/content/article/2008/05/15/AR2008051504007_pf.html. (last visited June 20, 2011).

³² See “EU Awards Galileo Satellite Navigation Contracts,” *BBC News*. January 7 2010. Found at: <http://news.bbc.co.uk/2/hi/science/nature/8442090.stm> (last visited June 20, 2011). (Herein “*BBC News*, January 7, 2010”). For general information on the Galileo navigation system, see the

into \$40 million per satellite launch. A commercial launch would also require launch insurance, which is typically 10% of the insured satellite value.³³ Based on these estimates, the total cost for building and launching satellites for a commercial GPS network would be approximately \$5.7 billion. See Table 1.

Further, the cost of infrastructure investment and annual operations over 30 years are expected to be close to \$1.1 billion each. In 2007, building the ground base infrastructure to accompany the Galileo satellite system—including ground control infrastructure, systems engineering and procurement—was expected to cost €745 million.³⁴ According to 2010 estimates by UK think tank, *openeurope*, the cost of annual operations after deployment is expected to be €750 million a year.³⁵ Again applying the current exchange rate, I estimate the cost of infrastructure and the cost of annual operations to be \$1.1 billion each.³⁶ Assuming a 15% rate of return on such a risky venture, the present value of 30 years of maintenance is close to \$8 billion. The present value of replacement satellites, including launch and insurance costs, is \$576 million.

Finally, a commercial GPS satellite network would likely require additional satellite licenses worth about \$2 billion. The U.S. Government's GPS system uses a dedicated band of spectrum that is more than 50 MHz. In order to transmit signals, a commercial GPS network may also need approximately 50 MHz of commercial satellite spectrum.³⁷ As discussed previously in this paper, spectrum is a scarce resource and it would be difficult to get access to the wide bands of spectrum needed for such a venture. While commercial satellite spectrum licenses are not frequently traded, comparable spectrum is

Galileo Navigation website maintained by the European Space Agency (ESA). Found at: <http://www.esa.int/esaNA/galileo.html> (last visited June 21, 2011).

³³ By one estimate, satellite insurance can be as low as 10% - 13% of insured satellite value. See Selding, Peter B. de. "Insurance Premiums Stay Float Despite W3B Satellite Failure," *Space News*. May 20, 2011. Found at: http://www.spacenews.com/satellite_telecom/110520-insurance-premiums-flat.html (last visited June 20, 2011). (Herein "*Space News*, May 20, 2011"). For the purposes of this paper, I assume that the entire satellite value is insured.

³⁴ This excludes an additional \$1.5 billion in cost overruns that were estimated by 2010, as well as governmental administrative costs and the costs of running GALILEO's satellite navigation predecessor, EGNOS. See "Galileo: Recent Developments," House of Commons Transport Committee. November 7, 2007. Found at: <http://www.publications.parliament.uk/pa/cm200708/cmselect/cmtran/53/53.pdf> (last visited June 20, 2011). (Herein "House of Commons Transport Committee, November 7, 2007"). See also "Lost in Space: How the Cost of the EU's Galileo Project Has Skyrocketed," Open Europe. October 17 2010. Found at: <http://www.openeurope.org.uk/research/galileo2010.pdf> (last visited June 20, 2011). (Herein "Open Europe, October 17, 2010").

³⁵ See Open Europe, October 17, 2010.

³⁶ I consider these estimates conservative since, by some reports, these figures are optimistic and the cost associated with GALILEO continue to rise. See Galileo (satellite navigation) on Wikipedia. Found at: [http://en.wikipedia.org/wiki/Galileo_\(satellite_navigation\)](http://en.wikipedia.org/wiki/Galileo_(satellite_navigation)) (last visited June 18, 2011).

³⁷ A commercial satellite system will require spectrum for a wideband transmission signal and some amount of adjacent guard bands. The total amount of spectrum required is equal to the amount of spectrum not available to other users as a result of the commercial GPS system. It may be the case that the total requirements for a commercial system are less than 50 MHz. If so, the value of their allocation would be reduced proportionately.

generally valued around \$2 billion. For instance, Sirius XM Radio holds about 50 MHz of contiguous satellite spectrum licenses for transmission of its satellite radio services. These licenses are similar to the type of spectrum a commercial GPS system would require. According to company filings, these licenses are worth just over \$2 billion.³⁸ This is consistent with other satellite spectrum transactions. For instance, the bankrupt MSS provider TerreStar Networks Inc. is expected to be bought at auction for \$1.37 billion.³⁹ Assets of a similar bankrupt MSS operator, DBSD North America, were purchased for \$1.4 billion in March.⁴⁰ The major assets of both companies are licenses for 20 MHz of S-Band spectrum.⁴¹

All told, the system is expected to cost \$18 billion in present value terms. This represents just over half the spending on GPS and is 56% of the value currently estimated of operating the Galileo system for 20 years.⁴² This value represents the total investment in a U.S. commercial network, rather than the value to any one user. This analysis does not attempt to determine how such costs would be distributed to individual users. While there are various ways the GPS commercial industry might arrange to invest in such a network, the critical point is that such expenditure would have to be made by the industry players. By enjoying free access to the U.S. Government GPS network, these users are able to forgo this cost and likely receive better service than on a commercial network.

³⁸ This estimate is based on the asset value of commercial satellite spectrum licenses held by Sirius/XM. See “Sirius XM Radio Inc. and Subsidiaries Notes to Consolidated Financial Statements,” Sirius XM 10-K. 2010, p. F-19.

³⁹ Humer, Caroline; Nick Brown. “Exclusive: Terrestar nears bid pact,” *Reuters*. June 14, 2011. Found at: <http://www.reuters.com/article/2011/06/14/us-terrestar-exclusive-idUSTRE75D6AA20110614> (last visited June 22, 2011).

⁴⁰ Humer, Caroline. “Dish approved to buy satellite company DBSD,” *Reuters*. March 15, 2011. Found at: <http://www.reuters.com/article/2011/03/15/us-dish-dbsd-idUSTRE72E61N20110315> (last visited June 22, 2011).

⁴¹ Goldstein, Josh. “Harbinger, Solus challenge Dish's Ergen for spectrum assets,” *FierceWireless*. March 3, 2011. Found at: <http://www.fiercewireless.com/story/harbinger-solus-challenge-dishs-ergen-spectrum-assets/2011-03-03#ixzz1Q1xrslWp> (last visited June 22, 2011).

⁴² As of October 2010, the total cost of building and operating Galileo for 20 years was estimated to be €22.2 billion (\$32 billion). See Open Europe, October 17, 2010.

Table 1. Estimated Satellite Network Cost for Commercial GPS System

[1]	Satellite Research and Development	\$	\$1,000,000,000
[2]	Cost of Satellite	\$	\$200,000,000
[3]	Total Cost of 18 Satellites	\$	\$3,600,000,000
[4]	Satellite Launch Cost	\$	\$40,000,000
[5]	Total Launch Cost for 18 Satellites	\$	\$720,000,000
[6]	Total Launch Insurance Cost	\$	\$360,000,000
[7]	Total Cost of Building and Launching GPS Satellites	\$	\$5,680,000,000
[8]	Ground Infrastructure and Operation	\$	\$1,100,000,000
[9]	Annual Operating Cost of Maintaining Satellite Network	\$	\$1,100,000,000
[10]	Rate of Return	%	15%
[11]	Net Present Value of Operating Cost (30 Years)	\$	\$8,322,577,600
[12]	Net Present Value of Satellite Replacement	\$	\$575,146,191
[13]	Potential Cost of Satellite Spectrum Licenses for GPS Network	\$	\$2,000,000,000
[14]	Total Cost of Building and Operating a Commercial GPS Network	\$	\$17,677,723,791

Sources and Notes:

[1] & [2]: Estimate based on Inside GNSS, May 16, 2008

[3]: [2] x 18

[4]: Estimate based on BBC News, January 7, 2010

[5]: [4] x 18

[6]: [3] x 10%; based on Space News, May 20, 2011

[7]: [1] + [3] + [5] + [6]

[8]: Estimate based on House of Commons Transport Committee, November 7, 2007

[9]: Estimate based on Open Europe, October 17, 2010

[10]: Assumption

[11]: Net Present Value of [9] based on [10] over 30 years

[12]: Net Present Value of replacement satellites, launch and insurance costs (\$4.68 billion) in 15 years based on [10]

[13]: Estimate based on value of licenses for Sirius XM spectrum

[14]: [7] + [8] + [11] + [12] + [13]

IV. VALUE OF ACCOMODATION TO GPS INDUSTRY

By not deploying receivers with sufficient filters, the GPS industry has enjoyed an advantage of lower costs at the expense of new L-Band users. This benefit to the GPS industry comes at substantial cost of tying up at least 20 MHz of spectrum outside the GPS spectrum allocation (the 10 MHz in the upper L-Band that will go unused and the 10 MHz of spectrum paired with it that will also go unused during the accommodation period) worth approximately \$6 billion. In essence, due to their lack of filters GPS uses that spectrum. A reasonable question is then what value has the GPS industry enjoyed by

using the adjacent L-Band spectrum? The value of utilizing this spectrum for GPS is equivalent to the cost avoided by not outfitting GPS devices with adequate filtering signals.

In the future, however, these GPS devices will need to be equipped with better filters. The question then remains, given several years of LightSquared accommodation, what will be the cost of ensuring that all GPS devices are effectively protected once LightSquared does begin using this spectrum? This future cost is reflective of the past benefit of not deploying better filters. The existing stock of GPS devices in the U.S. can be sorted into two groups: (1) devices that will be replaced in the next several years by newer devices with upgraded filters, and (2) more permanent devices that will have to be retrofitted with new filters.

For devices that will be replaced in the normal course of business, the cost is equal to the cost of installing filters into these new devices during manufacturing. According to one analyst estimate, the added cost of an improved filter will be \$0.30 per device.⁴³ For devices that will have to be retrofitted, the cost is equal to that of installing new filters. While the filter will likely be the same cost, there will be some added cost of retrofitting equipment. This cost will probably depend on the device and its accessibility.

There are many subgroups of GPS devices to consider: aviation, cellular, general location and navigation, high precision, space based, network, and timing devices. Since the average lifespan of a cellular device is 18 months,⁴⁴ these devices will likely be upgraded in the normal course of business over the next several years. Further, the cost of updating these devices may be \$0, because many of these devices would already be installed with such filters due to the interference between the cellular service and GPS.⁴⁵ Most personal navigation devices will also likely be replaced over the course of several years. According to one market report, there are expected to be 128 million personal navigation devices in use world wide by 2014.⁴⁶

Although the total cost per device will be higher for devices that are retrofitted—including aviation, high precision, network and timing devices—the number of these devices in use is much smaller. For instance, as of March 2011 there were a total of 224,475 active general aviation aircraft in the U.S., each required to have GPS receivers.⁴⁷ Given the wide range of GPS applications and devices, numerous estimates would be necessary to determine the cost of retrofitting GPS devices in the U.S. It is

⁴³ See footnote 22.

⁴⁴ See “Cell Phone Life Cycle” webpage of the Environmental Literacy Council website. Found at: <http://www.enviroliteracy.org/article.php/1119.html> (last visited June 20, 2011).

⁴⁵ See, for instance, Qualcomm Comments to FCC, January 21, 2011.

⁴⁶ See Kim, Danny. “Smart Phones to Surpass PNDs in Navigation Market in 2014,” *iSuppli*. September 1, 2009. Found at: <http://www.isuppli.com/automotive-infotainment-and-telematics/news/pages/smart-phones-to-surpass-pnds-in-navigation-market-in-2014.aspx> (last visited June 20, 2011).

⁴⁷ See “Active General Aviation Aircraft in the U.S. 1973-2011” webpage on the Federal Aviation Administration website. March 2011. Found at: <http://www.aopa.org/whatsnew/stats/aircraft.html> (last visited June 20, 2011).

clear, however, that this cost will be equal to a fraction of the value of LightSquared spectrum deployed for wireless broadband services.

V. CONCLUSION

Spectrum is a scarce resource that should be put to the most valuable use possible. LightSquared's proposed 4G terrestrial LTE network will create approximately \$12 billion in direct economic value to the economy in addition to the MSS services it already offers to commercial and government users, and many times that in benefits to consumers. Other valuable uses of spectrum include the devices and services enabled by the U.S. GPS satellite system utilizing the 1559 MHz – 1610 MHz band adjacent to LightSquared's L-Band spectrum. By using the GPS satellite network free of charge, U.S. commercial GPS users already enjoy substantial implicit subsidies worth close to \$18 billion. Further, by not ensuring that GPS devices adequately filter L-Band transmissions beyond the GPS allocation, the GPS industry has been effectively using 10 MHz of adjacent L-Band spectrum.