Spectrum Allocation Policy

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EXECUTIVE SUMMARY

Regulation of vital finite resources, like water, is never easy. The allocation and distribution of the electromagnetic spectrum is no different. Of particular concern is managing the increasing demand on the parts of the electromagnetic spectrum with commercial interests, for applications such as conducting telecommunications and downloading images from remote sensing satellites.

In predicting demand for these vital parts of the spectrum, government regulators failed to foresee significant changes such as the propagation of large commercially-developed satellite constellations and the immense growth in market demand for space-based imagery. In light of concerns from the United States satellite industry, this study re-examines the current regime for frequency allocation of the electromagnetic spectrum with emphasis on the X-band, which has unique natural characteristics that are valuable to the commercial remote sensing industry. In doing so, it outlines the concerns of all major players and considers conflicts between federal and commercial interests. The study then presents policy options which provide suggestions for reconciling an impending crisis in the regulation and allocation of the electromagnetic spectrum, a finite and scarce resource and a crucial asset for the United States government and commercial sector.

First, an analysis of current domestic protocols is presented and an argument is made for review of implementation of regulations that dictate government and commercial interests should be considered “co-primary” when allocating certain frequencies. The study highlights that the National Telecommunications and Information Administration (NTIA) has been consistently favoring government interests over commercial interests in its evaluations. The study also evaluates policy innovations to alleviate noise accumulation issues and other conflicts which have resulted from sudden increase in demand and usage of the electromagnetic spectrum.

At the end of the study, we make some recommendations for a long-term sustainable policy structure, including: increasing awareness; adoption of an enhanced licensing regime; smart spectrum; use of hub-satellite concept; and accountability of federal agencies. These recommendations would ensure optimal use of the invaluable resource. Improving the regulation

of remote sensing technologies, particularly with respect to Earth observation, holds the promise of providing numerous benefits to a wide range of terrestrial activities such as weather forecasting, natural resource utilization, emergency response efforts, and navigation. Optimizing spectrum usage in any way is invaluable to all people on Earth and vital to United States economic, diplomatic, and humanitarian interests.

Introduction and Background

This section outlines the activities and recent developments of the commercial remote sensing industry. It focuses on escalating issues arising from recent market growth where a significant increase in the number of players has caused overcrowding of the spectrum and rising issues with interference. Research findings suggest that one of the root causes lies in the fact that certain government agencies charged with regulating spectrum have taken a competitive position with the industry, favoring government demand instead, even though they have been mandated with promoting industry growth. Technical and policy issues are discussed with respect to establishing the background of the problem.

The Commercial Remote Sensing Industry

Remote sensing, most commonly referred to in the space industry as Earth observation (EO), involves the collection of information about the Earth, in most cases in the form of imagery in different bands (optical, infrared, ultraviolet, etc.), without direct contact with the planet. EO most often refers to data acquired from satellites, but can also be collected from other remote sensing platforms such as aircraft and can be supplemented by surface and subsurface measurements and mapping (International Journal of Applied Earth Observation and Geoinformation, 2017).

Sensors mounted on these satellites then collect information about the Earth by detecting energy reflected from the Earth or detecting what energy is not reflected back to the sensor, which can reveal chemical composition, local electromagnetic activity, and other planetary features. The sensors are of two types: passive and active. Passive sensors detect energy that is naturally emitted by objects on the Earth. Active sensors first emit energy to the Earth, and then detect the reflected energy. Remote sensing has several applications such as land-cover mapping, ocean monitoring, weather forecasting, disaster management, exploration of natural resources, environmental management, and monitoring other global changes related to geological, environmental, and human activity. These applications increasingly involve data analysis and value-added services on top of the raw data provided by remote sensing platforms.

For government or commercial players to conduct remote sensing, each needs an allocation of the electromagnetic spectrum to communicate with and relay images from the satellite. Spectrum allocation is essential to all forms of remote sensing and other satellite uses, since only spectrum can be used for remote, wireless communications of any kind. For the greater part of the past century, since the first satellites were blasted to orbit, spectrum for remote sensing was predominantly used by government agencies for civil and defense applications. In the last several decades, a budding commercial space industry has caused a significant rise in commercial remote sensing, conducted by private companies.

In the United States, where the majority of major satellite operators reside, spectrum is needed for communication by ground stations with the satellites and for downloading of images from the satellite by ground stations, which then disseminate the information on Earth to government agencies, companies, and individuals. Put differently, the diverse benefits obtainable from remote sensing would not be possible without spectrum. Commercial remote sensing is conducted by private companies, while civil remote sensing is done by government agencies. All commercial remote sensing companies in the United States – as well as those wishing to do business in the United States – must have a license from the United States government to operate. The license includes an agreement to follow the instructions of the United States government (National Oceanic and Atmospheric Administration, n.d.). Licensing, operations and regulatory authority of American satellites is made law by the National and Commercial Space Programs Act of 2010, Title 51 of the United States Code, while licensing is controlled by NOAA's Commercial Remote Sensing Regulatory Affairs. To this day, the satellite community feels it is being stifled by both burdensome regulations and regulatory loopholes that cannot cover newer systems and constellations. In "The satellite operator community voiced major concerns over these new restrictions with NOAA" (Schlinger & Leshner, 2016).

Today, commercial remote sensing increasingly means the data analysis that can be performed with the information gathered by sensors on satellites: remote sensing has been used to detect illegal oil refineries in Nigeria (Balogun, 2015), calculate air and ocean ship traffic, and predict crop yields (Kondylis & Burke, 2015). These resources are also used in disaster management to help coordinate aid efforts where they would have the greatest effect, and to get reliable information in near-real time when ground infrastructure fails. New entrants to the commercial remote sensing market seek to disrupt the traditional model of large, expensive, unique satellites, with small, relatively low-cost and "mass-produced" satellites (Erwin, 2017). These new entrants are challenging the existing model, but both of these models still rely on ever more use of spectrum to transmit ever more data across increasingly large areas of the Earth. All of these models therefore have the potential to increase interference of signals across the globe if not managed well. In 2016, for example, EO services revenue grew by 10%, which was more than twice that of other space-based services. Furthermore, unlike other services, planned constellations of EO satellites will increase their numbers by three times the current amount of operational EO satellites today (Satellite Industries Association, 2016).

Figure 1: EO Satellites (Source: State of the Satellite Industry)

Operational / Planned

		High Resolution (<1m)	High revisit time (<1dy)	Sensor Description	System or Constellation Size	Satellite Mass (kg)
Large Sats	**Airbus D&S**	•		Optical and radar	4	1,000
	DigitalGlobe	•	•	Optical	5	2,800
	DMCii	•		Optical	6	450
	ImageSat	•		Optical	3	350
	MDA			Radar	4	1,300
	UrtheCast	•	•	Opt & rad (planned), video	24	1,400
Small Satellites (<200 kg)	**Aquila Space**	•	•	Optical and radar	30	6
	BlackBridge	•	•	Optical	5	150
	BlackSky Global		•	Optical	60	50
	DigitalGlobe/TAQNIA		•	Optical	6	TBD
	XpressSAR	•		Radar	4	TBD
	GeoOptics		•	Radio occultation	25	100
	Hera		•	Optical	48	24
	Iceye	•	•	Radar	50	<100
	OmniEarth		•	Optical	15	110
	PlanetiQ	•	•	Radio occultation	12	22
	Planet Labs		•	Optical	100	3
	Satellogic	•	•	Optical	300	35
	Spire Global		•	Radio occultation	50	3
	Terra Bella	•	•	Optical and video	24	120

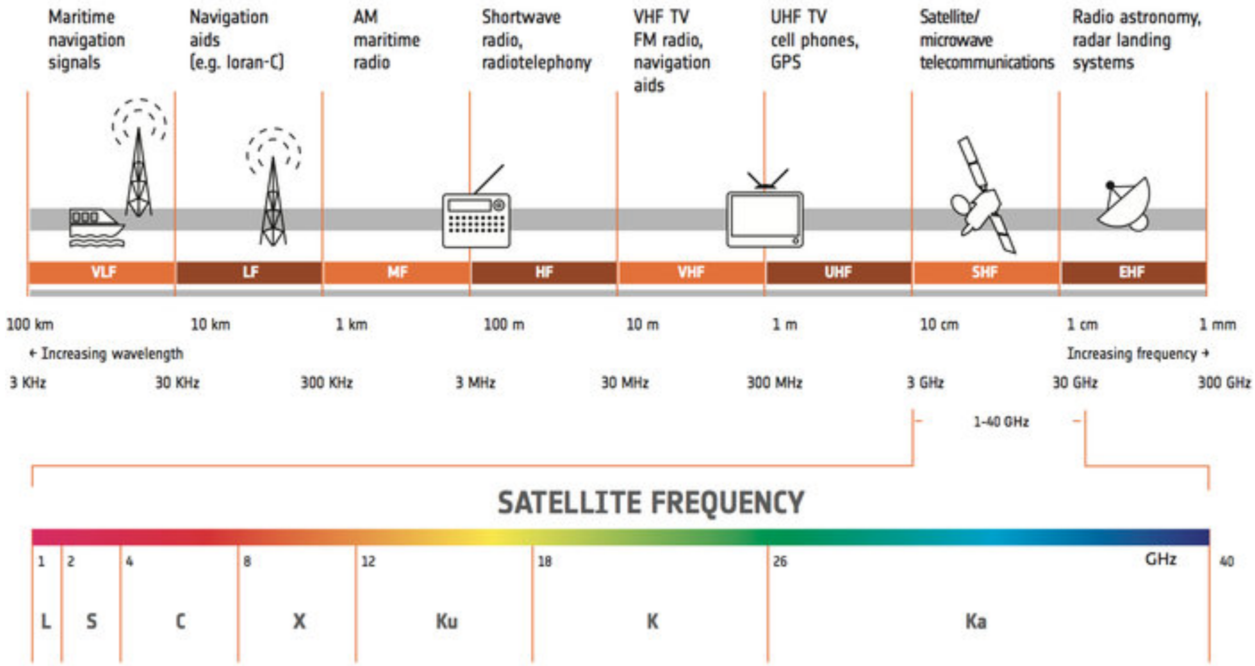
As spectrum becomes more crowded, both passive and active (Spencer & Ulaby, 2016) sensors experience interference that cancel out or distort their readings as signals of the same frequency nullify each other. Increasing signal use both on Earth and in space makes this type of interference more common and increasingly likely, particularly in timely, globally persistent applications, such as remote sensing from space. Although the degree and intensity of interference varies by band and location, this fundamentally disrupts their ability to do business and provide trustworthy information.

Electromagnetic Spectrum: A Finite Resource

Technology has greatly improved the way we work, live and play – and much of it has to do with utilizing the electromagnetic spectrum. The electromagnetic spectrum refers to the full range of electromagnetic radiation and also the distribution of this radiation emitted or absorbed by a given object.

Utilizing the electromagnetic spectrum has enabled such advances in human communication and our understanding of Earth systems as the development of wireless communications and the development of technologies that allow humans to monitor natural resources and the environment, rapidly track developments in response to natural and human-caused disasters, better predict weather and climate forecasting, and follow large scale developments in human migrations and warfare. All of these capabilities can be improved significantly with even more effective and efficient utilization and management of the electromagnetic spectrum.

Figure 2: Applications of Satellite Frequencies (Source: European Space Agency)

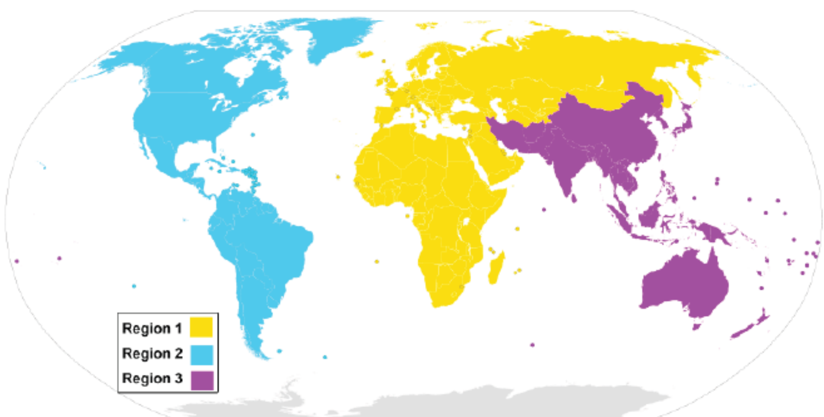


Regulation of the spectrum is both a science and an art. A scientific understanding of the frequency spectrum is necessary for assignment of frequency use. An inefficient assignment can lead to under-utilization and/or congestion. Congestion causes interference, hence low-quality services, since too many users are operating on the same frequency and cancelling each other out. It is an art because there are often competing interests for bands of frequencies, and no scientific method for making allocations. For example, if African citizens are primarily connected to the global economy through mobile telecommunication networks, international regulators must ask themselves questions such as whether these human beings should be allocated more spectrum for disaster management or access to economic opportunity (ESOA, n.d.). Regulators need to be able to ensure an optimum use of the spectrum and allocate this scarce resource in ways that ensure the best interest of the final users – the citizens.

As frequency spectrum is not delimited by artificial country boundaries, the International Telecommunications Union (ITU), an UN specialized agency, allocates frequency spectrum to different services. One of its missions is “to ensure rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including those using satellite orbits, and to carry out studies and adopt recommendations on radiocommunication matters." A service could be allocated on a primary or secondary basis. On a primary basis, the service gets priority access to a band of spectrum and no other service is allowed to interfere with the primary service. A service on a secondary basis takes second place on a band of spectrum to a primary service. Two or more services can also have co-primary status within a band. In such cases, the services are supposed to be considered equal in importance. When designated as exclusive, that group of user is the only one that can utilize that frequency.

Furthermore, the ITU has divided the world into three regions, and allotted frequencies to these regions. Figure 3 shows the division of the regions. The United States, as well as other countries in the Americas, falls under Region 1.

Figure 3: Regions of the ITU (Source: PolicyTracker)



Within a country, the national spectrum administration assigns a frequency band to an entity for use by a specific technology. This is called licensing or authorization. In the U.S., there are two regulatory bodies. The National Telecommunications and Information Administration (NTIA) assigns and regulates frequencies for government agencies, while the Federal Communications Commission (FCC) assigns and regulates frequencies for commercial and non-governmental entities. Frequencies can be assigned through a straight application process, hearing, lottery or by auctioning. Table 1 is an overview of frequency allocation in the U.S. The bandwidth description and frequency range are part of an international standard, while the service and band apply specifically to the U.S.

Table 1: U.S. Spectrum Chart (Source: FCC)

Bandwidth description	**Frequency range**	**Service**	**Band**
Extremely Low Frequency (ELF)	0 to 3 kHz		
Very Low Frequency (VLF)	3 kHz to 30 kHz	Radio navigation and maritime/aeronautical mobile	9 kHz to 540 kHz
Low Frequency (LF)	30 kHz to 300 kHz		
Medium Frequency (MF)	300 kHz to 3 MHz	AM radio broadcast	540 kHz to 1630 kHz
		Traveler's information service	1610 kHz
High Frequency (HF)	3 MHz to 30 MHz	Shortwave broadcast radio	5.95 MHz to 26.1 MHz
Very High Frequency (VHF)	30 MHz to 300 MHz	Low band: television band 1 (channels 2-6)	54 MHz to 88 MHz
		Mid-band: FM radio broadcast	88 MHz to 174 MHz
		High band: television band 2 (channels 7-13)	174 MHz to 216 MHz
		Super band (mobile/fixed radio and television)	26 MHz to 600 MHz)
Ultra-High Frequency (UHF)	300MHz to 3 GHz	Channels 14-70	470 MHz to 806 MHz
		L-band	500 MHz to 1.5 GHz
		PCS	1.85 GHz to

			1.99 GHz
		Unlicensed PCS devices	1.91 GHz to 1.93 GHz
Super-High Frequencies (SHF) (microwave)	3 GHz to 30GHz	C-band	3.6 GHz to 7.025 GHz
		X-band	7.25 GHz to 8.4 GHz
		Ku-band	10.7 GHz to 14.5 GHz
		Ka-band	17.3 GHz to 31 GHz
Extremely High Frequencies (EHF) (millimeter wave signals)	30 GHz to 300 GHz	Additional fixed satellite	38.6 GHz to 275 GHz
Infrared radiation	300 GHz to 430 THz		
Visible light	430 THz to 750 GHz		
Ultraviolet radiation	1.62 PHz to 30 PHz		
X-rays	30 PHz to 30 EHz		
Gamma rays	30 EHz to 3000 EHz		

Technical Problem: Interference

One of the properties of electromagnetic waves is interference. When two waves align perfectly and add up, it is called constructive interference. Constructive interference produces a larger wave than the original two, and has higher amplitude (power). When two waves are not aligned and add up, it is called destructive interference. Destructive interference reduces the power of the combined waves, and sometimes could totally cancel out both waves. Since waves are used to convey information, neither type of interference is beneficial to both parties.

The ITU defines interference as “the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy" (ITU, 2012). Several radiocommunication services are affected by interference, particularly passive Earth observation and astronomy. Table 2 shows a list of the most relevant frequency bands used for passive remote sensing and their main Earth observation application, while Table 3 shows the bands used for active remote sensing.

Table 2: ITU Frequency bands used for passive remote sensing (Source: Misra & de Matthaeis)

Bands (GHz)	**Application**	**Interference level and sources**
1.34-1.40; 1.40-1.427	Soil moisture, sea surface Salinity, sea surface wind, vegetation index	High; out of band emissions mostly from air surveillance radars.
6.425–7.25	Soil moisture, sea surface temperature, precipitation	Moderate (especially over the U.S.A.)
10.6–10.7	Precipitation, cloud liquid water, sea surface wind speed, sea surface temperature	Moderate (especially over Europe)
18.6–18.8	Precipitation, cloud liquid water, snow cover, sea surface wind speed, sea ice	Moderate; potentially from satellite TV service signals.
22.21–22.5; 23.6–24	Atmospheric water vapor, Sea surface wind speed, sea ice, precipitation, snow cover	Moderate; vehicle anti-collision radars
31.3–31.8; 36–37	Precipitation, cloud liquid water, snow cover, sea surface wind speed, sea ice	Low; new sources observed off oil platforms near the Indian subcontinent
50.2–50.4;	Atmospheric temperature	Moderate: potential for

51.4–59.3	profiling	RFI due to spectrum sharing rules at 55–57

Table 3: Frequency bands used for active remote sensing (Source: Spencer & Ulaby)

Band designation	**Frequency band allocation**	**Application**
P band	432–438 MHz	Radiolocation, amateur, amateur satellite, fixed, mobile, Industrial Scientific and Medical (ISM), space operation service (Earth-to-space), aeronautical radio navigation
L band	1,215–1,300 MHz	Radiolocation, Radio Navigation Satellite Services (RNSS), amateur (secondary)
S band	3,100–3,300 MHz	Radiolocation
C band	5,250–5,570 MHz	Radiolocation (active and secondary), Aeronautical RNSS
X band	8,550–8,650 MHz	Radiolocation
X band	9,300–9,900 MHz	Radiolocation, radio navigation Fixed
Ku band	13.25–13.75 GHz	Aeronautical RNSS, radiolocation
Ku band	17.2–17.3 GHz	Radiolocation
K band	24.05–24.25 GHz	Radiolocation, amateur (secondary)
Ka band	35.5–36 GHz	Radiolocation, MET-AIDS, fixed, mobile
W band	78–79 GHz	Radiolocation, amateur, amateur-satellite, space research (space-to-Earth)
W band	94–94.1 GHz	Radiolocation
mm band	133.5–134 GHz	Radiolocation
mm band	237.9–238 GHz	Radiolocation

Juxtaposing Table 1, 2 and 3, one observes that a couple of applications can be used in multiple frequency bands. Hence, for optimum use, the spectrum administrations (both international and national) allocate and/or assign specific bands for specific uses, after a study of the propagation characteristics of the band. Also, one may observe that the X-band is conspicuously missing from Table 2. The reason is that only active devices (such as radar) are used in the X-band.

The X-band is not only used for remote sensing; its propagation characteristics make it suitable for critical communication. It is allocated primarily for fixed-satellite service and mobile satellite service. The ITU has assigned portions for deep space communication. X-band has unique characteristics which make it attractive for both federal and non-federal users. It is not affected by rain fade; has lower problem of interference (because satellites in this band have more spacing between them); and provides high data rates. Table 4 highlights some of the advantages of the X-band over other bands. In some countries (such as the U.S.), the X-band is reserved for use by the federal government. Within the U.S., NTIA oversees the use of the band. It is used in critical applications such as air traffic control, deep space communication, and weather monitoring. Most NASA deep space missions, such as the Mars Missions, communicate via the X-band (JPL, 2017).

Table 4: Advantages of X-band Over Other Bands (Source: XTAR)

Frequency Band	C	X	Ku	Ka	Mil Ka
Weatherproof	✓	✓			
High-Throughput (easily supports voice/data/imagery/HD video)		✓	✓	✓	✓
Excels with Small Antennas/Low Cost (extremely high MHz-Mbps efficiency)		✓			✓
High Link Availability (99.9%)	✓	✓			

Generally, new services and applications would require new band assignment or increased bandwidth. Private sector activities have also increased the demand of spectrum. This can raise a problem of interference with existing services. Frequency coordination, a bilateral/multilateral technical and regulatory process, which was introduced by the ITU to resolve the problem of interference, has been useful but it takes a long time due to the series of back-and-forth exchanges needed to reach coordination. It is conducted in working groups at ITU that cooperatively reach consensus, but specifically refers to specific actions, such as informing operators that use the same bands of future plans, to receive comments, and agree on technical parameters before bringing a system into use. National spectrum allocators also use this process. However, those with more money and lobbying experience can manipulate this process: for example, terrestrial services have won several victories in the last decades and gained spectrum formerly allocated for satellite use. In response, satellite operators since 2007 have formed the Satellite Spectrum Initiative to unify satellite operators, as well as maritime, aid organizations and consumer groups that rely on satellite services against the increasingly powerful lobby of major telecommunications monopolies (Satellite Spectrum Initiative, n.d.).

Policy Problem

One of the most challenging issues for the commercial Earth observation (EO) satellite industry stems from how the United States spectrum allocation authority is structured. The U.S. government divided the usage of the electromagnetic spectrum into two broad areas: federal and non-federal. Federal usage is meant to meet all the frequency needs of the federal government, including the military. Non-federal usage includes everything else, such as commercial, personal, and state and local government uses.

The Communication Act of 1934[1], signed by President Franklin D. Roosevelt, established the statutory background for the division of the regulatory powers. This act created the Federal Communication Commission (FCC) and granted it "authority with respect to interstate and foreign commerce in wire and radio communication" (US Congress, 1934). Section 301 of the Act required usage of radio communication to be licensed by the newly created FCC. Furthermore, Section 305 excluded radio stations belonging to and operated by the federal government from Section 301, and transferred the regulatory authority of the federal government's spectrum allocation to the President. In order to exercise this authority, President Jimmy Carter created NTIA in 1978. The two agencies, the FCC reporting to Congress and NTIA reporting to the White House, collectively have the authority of allocating the full United

[1] The Communication Act of 1934 later became Chapter 5 of Title 47 of the United States Code.

States frequency spectrum.

The main problem with the bi-agency approach is that because electromagnetic frequency is a limited resource, the two agencies and their respective stakeholders compete for allocation priority. The same frequency cannot be assigned to multiple users and for multiple purposes. Also, certain frequencies are better suited for specific uses. For example, as explained above, due to the Earth's atmosphere and weather system disrupting most other frequencies, the X-band, from 8 GHz to 12 GHz, is the most useful spectrum for remote sensing satellites and high-fidelity telecommunications. Furthermore, the increase in the number of users and applications of satellite technology create more severe competition for increasingly congested frequency bands of spectrum, such as the X-band.

Currently, federal use is designated as primary or exclusive in more portions of the frequency spectrum than non-federal uses. When designated as primary, secondary users cannot interfere with the signal. When designated as exclusive, that group of users is the only one that can utilize that frequency. Where possible, frequency is shared by the two sectors and designated as co-primary; in such cases, both sectors are supposed to be considered equal in importance. According to NTIA, about 18.1% of the spectrum is designated as Federal Exclusive, 51.5% is designated as Federal Primary, and 30.4% is designated as Non-Federal Exclusive (Nebbia, 2009). Table 5 shows the breakdown of designation of the X-band. 24.8% of this band is exclusively for federal use. A larger 36.0% is designated as federal primary and 30.7% to the non-federal primary. Lastly, only a small portion of 8.5% is designated as co-primary.

Although a sizeable portion seem to be available for non-federal users, in practice, federal agencies take uncontested priority over the primary and co-primary allocations. Therefore, federal users enjoy priority over approximately 70% of the X-band spectrum, and non-federal users are left with only 30%. With the rapid growth of the commercial sector in satellite communication and other space applications, non-federal users are left to scramble and compete for limited frequencies while being superseded by federal users in bands they understood they could share evenly and fairly under the so-called co-primary status.

Table 5: Designation of X-band (Source: FCC)

From (MHz)	To (MHz)	Federal	Non-federal
7,145	7,190	Exclusive	
7,190	7,235	Exclusive	
7,235	7,250	Exclusive	
7,250	7,300	Exclusive	
7,300	7,450	Exclusive	
7,450	7,550	Exclusive	
7,550	7,750	Exclusive	
7,750	7,850	Exclusive	
7,850	7,900	Exclusive	
7,900	8,025	Exclusive	
8,025	8,175	Exclusive	
8,175	8,215	Exclusive	
8,215	8,400	Exclusive	
8,400	8,450	Primary	Secondary
8,450	8,500	Co-Primary	Co-Primary
8,500	8,550	Primary	Secondary
8,550	8,650	Primary	Secondary
8,650	9,000	Primary	Secondary
9,000	9,200	Co-Primary	Co-Primary
9,200	9,300	Co-Primary	Co-Primary
9,300	9,500	Primary	Secondary
9,500	9,900	Primary	Secondary
9,900	10,000	Primary	Secondary
10,000	10,500	Primary	Secondary
10,500	10,550	Primary	Secondary
10,550	10,600	Secondary	Primary
10,600	10,680	Co-Primary	Co-Primary

10,680	10,700	Primary	Secondary
10,700	11,700	Secondary	Primary
11,700	12,200	Secondary	Primary

As non-government entities wrestle with this limited spectrum allocation for the non-federal sector, the federal government has been criticized for its inefficient use of the spectrum. In 2012, GAO reported on several causes for the inefficiency (U.S. Government Accountability Office, 2012). First, instead of actively researching and understanding the real frequency needs of the federal government, NTIA tends to rely heavily on each federal agency's expertise and request. The implication of this is that NTIA accepts the words of the federal agencies, instead of conducting independent spectrum management analyses of its own. Second, federal agencies receive spectrum allocation at no or minimal cost. This allows federal agencies to request and maintain ownership of frequencies as they see beneficial for their own agency, instead of the nation as a whole, thereby creating "artificial scarcity" (U.S. President's Council of Advisors on Science and Technology, 2012). Third, federal agencies do not have any incentive to free up or share the spectrum allocated to them. The lack of incentives, such as financial benefits or priority for future allocation when sharing allocated frequencies or returning unused frequencies, makes federal users more reactive, rather than proactive, to frequency management. They tend to only share or give up frequencies when they are directed by Congress or the White House. Lastly, federal agencies are not given the necessary conditions that would spur them to invest in the latest technologies that enhance spectrum efficiency. These factors lead to the federal government "warehousing," or restricting access without an immediate use of their own, frequencies that could otherwise be shared with or transferred to non-federal users. In response to such criticism, many federal agencies have claimed that much of their spectrum allocations are crucial to national security (Davison, 2010). However, such claims cannot be verified as each agency's specific use of the allocated frequency lacks transparency due to national security reasons.

Furthermore, in regard to the co-primary designation, whether the two sectors are considered to be equally important is questionable. During interviews conducted with industry participants, many of them shared that they found themselves to be considered secondary when competing with or sharing frequency with the federal government. This is particularly true of defense applications. Again, in such cases, the federal agencies have advocated their use of frequencies to be more important due to national security reasons. With the growth of new industries reliant on spectrum and the increased need for more frequency in the commercial sector, market participants are left to compete amongst themselves for whatever spectrum the federal government leaves behind. This creates an even higher barrier to entry for potential U.S. companies who want to access the U.S. market: companies could be driven to other countries where the policy climate favors them.

As such, the current spectrum management regime contradicts the U.S. National Space Policy in that it actually, even if unwittingly, discourages the competitiveness of U.S. companies. The 2010 National Space Policy, the last White House space policy, heavily emphasizes the importance of facilitating a competitive commercial space sector. Although the document is from the previous administration, President Trump has maintained the importance of supporting the commercial sector. As an example, below are two excerpts from the policy document that highlight the direction of the United States in regard to the "robust" commercialization of space:

- A robust and competitive commercial space sector is vital to continued progress in space. The United States is committed to encouraging and facilitating the growth of a U.S. commercial space sector that supports U.S. needs, is globally competitive, and advances U.S. leadership in the generation of new markets and innovation-driven entrepreneurship (3).
- Facilitate new market opportunities for U.S. commercial space capabilities and services, including commercially viable terrestrial applications that rely on government-provided space systems (6).

Unfortunately, the lack of frequencies allocated to non-federal sectors, the current inefficiencies in spectrum management by the federal government, and the unfair treatment of non-federal users in co-primary portions all contradict the National Space Policy's effort to foster commercial space industries, including but not limited to the remote sensing industry.

An interesting finding from our research was the perspective of the federal frequency users. The federal government officials interviewed for this study pointed out a factor in regard to commercial frequency allocation. They stated that the government has already spent billions of dollars since the 1960s to build such robust infrastructure that the United States currently has.

Therefore, reducing the range of the frequencies allotted to the government, thereby restricting the federal government's utilization, is not the most effective way to utilize the billions of dollars already invested. Furthermore, when asked about the lack of availability of frequencies for commercial uses, the government officials found it ironic that such an issue exists. They claimed that the commercial sector has been consistently increasing frequency allocation, little by little, since the time the two sectors began to meaningfully share the spectrum. One of the government officials, who requested to be anonymous, stated that the commercial companies are "cry babies." Clearly, there is a gap between the reality and the perceived reality of the needs of the commercial sector from the federal government's point of view.

NTIA and FCC have been consistently encouraged by stakeholders, such as Congress and the Government Accountability Office, to collaborate to ensure the effectiveness and the efficiency of the nation's spectrum allocation. The fragmented reality presents a different case. Although the scope of the collaboration has been better in recent years, they have not developed an overall joint strategic spectrum plan that combines both federal and non-federal usage (U.S. Government Accountability Office, 2016). This is an action that has been recommended by multiple stakeholders for many years and deemed necessary to resolve the inefficiencies in overall national spectrum management.

Policy Options

The end goal of controlling the amount of activity within a band of spectrum is simple: to keep the noise at the given band low enough for unimpeded usage. The question which policy must solve is how best to accomplish that goal. In order to find this solution, we have to consider both the physical attributes of spectrum usage by Earth observation satellites and the desires of the operators of these satellites, as well as the demand for competing uses. The physical attributes of a satellite broadcast can in turn be defined as the frequency of the transmission (where in the spectrum it occurs), the power of the transmission (the scale of its presence within the spectrum), the location of the transmission (what shape does the transmission take from point-to-point), and the timing of the transmission (for what duration does the transmission impact the spectrum).

The desire of Earth-observing actors is the greatest use of available spectrum, by communicating the most data possible without reaching the point at which noise degrades that data.

The simplest solution to the physical problem would be to cap the amount of power which can be cumulatively broadcast by all sources for a given band of spectrum, and then deny any licenses for usage of that spectrum once the threshold for detrimental noise has been reached. However, this solution is unacceptable to the stakeholders involved. New entrants would suffer the most as established players would rush to claim their spectrum allocations before the maximum tolerable noise is reached. Established players would also suffer, as they would lose their ability to modernize their orbital assets until confirmation that an existing satellite had been terminated and would no longer contribute noise to the spectrum. Imposing a simple moratorium to avoid noise accumulation would produce a market too volatile and stagnant to invest in. It would also discourage innovation, as companies would prioritize seizing spectrum when it is freed up by satellite termination rather than searching for ways to evolve their capabilities with continuous improvements.

Another possible solution would be an enhanced licensing regime through the incorporation of the space and time dimensions of spectrum usage into the current licensing regime. The noise produced by a transmission is focused in a finite area defined by the power of the transmission and the shape of the broadcasting source. Therefore, increasing the number of ground stations which satellites can transmit to would enable a greater number of simultaneous transmissions within a band to occur without the noise from the transmissions accumulating to the point of being a problem. Taking this methodology a step further, allotting spectrum usage by time has the potential to greatly increase the efficiency of current spectrum usage, although it would increase the complexity of licensing and managing spectrum by a proportional amount. Since the noise produced does not significantly persist after transmission has ceased, a given frequency and region could be shared by multiple parties over the course of a day. This is limited to systems which download data in dumps, however; satellites that conduct a continuous download have no unused transmission time to share with other systems.

A variation of the previous concept, the possibility of a ‘smart’ use of spectrum has begun to be discussed. Taking advantage of the continuing development of computing power and component miniaturization, it is possible for a satellite and ground station system to monitor the level of activity in various bands of the spectrum and transmit at the least “noisy” of available frequencies. A similar technology exists and is employed in many commercially available Wi-Fi network systems, so the technology has had an opportunity to develop and mature before being employed on multi-million dollar satellite systems.

If ‘smart spectrum’ use was to be adopted, then at a certain point of technology saturation it would surpass the enhanced licensing option mentioned previously in spectrum efficiency – although enhanced licensing would have the advantage in the short term, due to the fact that it is simply a policy change rather than a technological one and therefore can be applied to pre-existing systems. A concern that has been raised is the ability of smart spectrum to respond to crisis situations. If there was a sudden need for spectrum, possibly due to the need for imaging of a region that suffered a cataclysmic natural disaster or due to urgent communications as an armed conflict breaks out, it is unknown whether a smart spectrum system would be able to adapt quickly enough to avoid indirectly costing human lives. Fortunately, these concerns could be evaluated and alleviated with a gradual deployment of a smart spectrum system, testing it in microcosm before expanding across the spectrum.

The Defense Advanced Research Projects Agency (DARPA) believes it may be close to an even "smarter" solution: collaborative machine-learning software to autonomously allocate spectrum (Defense Advanced Research Projects Agency, 2016). DARPA's position on spectrum scarcity is that it is 'artificial' – a result of technological inefficiencies:

> Today’s approach, which is nearly a century old, isolates wireless systems by dividing the spectrum into rigid exclusively licensed bands, which are allocated over large, geographically defined regions. This approach rations access to the spectrum in exchange for the guarantee of interference-free communication. However, it is human-driven and not adaptive to the dynamics of supply and demand. At any given time, many allocated bands are unused by licensees while other bands are overwhelmed, thus squandering the spectrum’s enormous

capacity and unnecessarily creating conditions of scarcity. (DARPA, 2016, "What is the Spectrum Collaboration Challenge?")

To correct the "not adaptive," "human-driven" spectrum management framework of today, DARPA has organized a "Grand Challenge" (open to companies, universities, and even individuals) with total prizes of $3.75 million. It is the "world's first collaborative machine-learning competition" (DARPA, 2016) in that DARPA will not award the team that "dominates" others, but rather, as Program Manager Paul Tilghman says: "the team that shares most intelligently is going to win" (Hoffman, 2016). Unlike political and hardware solutions, software, particularly unsupervised predictive machine learning software, is becoming affordable and poised for a major breakthrough (Henke, Bughin, Chui, Manyika, Saleh, Wiseman, & Sethupathy, 2016). For example, DARPA's $3.75 million is paying for 30 different teams to simultaneously develop a similar technology (DARPA, 2016). DARPA writes confidently that under this framework it will be able to catalyze efforts at finding a permanent solution to spectrum management. "Competitors will [from 2017 to 2020] reimagine spectrum access strategies and develop a new wireless paradigm in which radio networks will autonomously collaborate and reason about how to share the RF spectrum" (DARPA, 2016).

More fundamental technological innovations could also be used to alleviate the problem of noise in the satellite-designated bands of the spectrum. For example, one of the major causes for concern regarding spectrum noise is the approach of “mega-constellations” of small satellites, all observing and transmitting simultaneously. Because noise generated is a function of the power of the transmission rather than any other factor of the satellite and because the power needed to transmit is the same for any source at a given frequency to cover the distance from Earth orbit to a ground station, each of a thousand small satellites in a mega-constellation will generate the same amount of noise as each of its much more massive and capable counterparts in a constellation of fewer than a dozen active satellites. However, this is based on the assumption that each small satellite is operating and transmitting as an independent system. To reduce the noise generated by a mega-constellation, an operator could choose to consolidate the many transmissions into a few, by first transmitting data from imaging satellites space-to-space to a hub server satellite. The space-to-space communications could be conducted in a different band than space-to-ground communications, such as via laser communication technology currently under development by NASA. This hub satellite would in turn download the work of many small satellites in a few or a single transmission(s), reducing the spectrum imprint of a mega-constellation to be more in line with that of existing constellations. The risk in such a centralized model is that the loss of a hub satellite can render many other satellites temporarily useless, if the mega-constellation is not designed with resiliency and redundancy in mind.

The "co-primary" issue derives from a failure of implementation of policy, rather than any physical problem such as the accumulation of noise within a spectrum band. Because both governments and companies use the X-band extensively, it is particularly relevant to this paper. In order to encourage the commercial development of the electromagnetic spectrum while preserving the opportunity for the government to use it for the national interest, key bands of spectrum have been designated as "co-primary". Within a co-primary band, government and commercial applications for usage are to be given equal evaluation to ensure that the finite resource of spectrum is distributed fairly, and not hoarded by a commercial entity as a squatting asset or by the federal government as a strategic reserve. However, the co-primary doctrine is not being upheld under the current licensing regime. While the FCC has done right by it, the other key body in the spectrum licensing process – the NTIA – has shown a clear preference for federal spectrum usage. Admittedly, this bias is understandable: The NTIA was designed from the very beginning to promote specifically federal interests in telecommunications. However, that has now led to the purposes of the co-primary doctrine and the purpose of the NTIA coming into conflict.

One way to resolve the co-primary conflict is to remove the spectrum licensing responsibility from the NTIA and make it exclusively the domain of the FCC. The NTIA would still be able to provide input through an inter-agency coordination process, but it would not be able to unilaterally upset the allocation of spectrum when its charter interferes with the greater spectrum allocation doctrine. Alternately, the federal government could choose the inverse case and revoke co-primary and perhaps even consolidate the spectrum licensing process wholly under the NTIA. While the second half of that scenario is extremely unlikely due to the different capabilities and expertise present within each agency, the changing of co-primary policy is definitely possible and would be an extremely undesirable outcome for SIA. While the current unfulfilled nature of the co-primary policy is not a desirable situation, care must be taken to ensure that attempting to change the status quo results in negative reaction and suspension of the co-primary policy altogether.

Another alternative which may present the most palatable compromise would be the formation of a permanent joint task group between the NTIA and the FCC. To counterbalance the federal bias in NTIA evaluations, the FCC half of this task group could take on a quasi-advocacy role on behalf of commercial applicants. In this way, while the majority of the membership of the task group would be expected to be objective actors under the co-primary doctrine, there would still be freedom for the NTIA to uphold the federal-preferential aspects of its charter. Furthermore, depending on how the FCC incorporates its commercially-biased component, it may be a way to encourage greater involvement in the spectrum coordination process on the part of commercial actors. This involvement would lead to greater understanding, which would then in turn enhance the competitiveness of American spectrum users globally. The cost of implementing this joint task group would be a slight disruption to the current spectrum licensing regime during the growing period the group, but the licensing process should subsequently accelerate.

Regardless of which of the two preceding options is pursued, awareness of the co-primary issue needs to be raised in order for change to be effected. As it stands, the policy community is essentially unaware of the concerns of stakeholders regarding NTIA's preference for its own agency directives over the greater spectrum policy regime. As a consequence, any complaints by parties applying through the spectrum licensing processes can be written off as isolated incidents. Once the policy community takes notice – academics start reviewing, journalists start publishing editorials, and the topic is raised in talks and seminars – these complaints will have a visible core to coalesce around. As the issue gains mass, it will eventually reach the point where it can overcome the institutional inertia that makes bureaucratic change a challenge. Therefore, a prerequisite to changing policy is establishing and increasing awareness of the failure of the current policy. The only danger comes from the risk of getting swept away by an issue; if one raises a new idea the expectation is that the party will continue to champion it to the end, which may not be how the party in question would prefer to use its resources – such as when lobbying between industries versus sharing with government.

Recommendations

Recommendation 1: Increase Awareness on Co-Primary Issue

One of the issues identified with the current spectrum allocation regime is the treatment of the frequencies that are designated as co-primary. As previously explained, the spectrum allocation regime of the United States designates federal and non-federal uses of each frequency as exclusive, primary, secondary, or co-primary. In the co-primary frequencies, both federal and non-federal sectors are to be treated as equally important and share the frequencies accordingly. Although the policy was formulated to give such equal opportunity, in reality, this is rarely the case. Industry participants have expressed concerns that in such frequencies, federal users are heavily favored and the equality does not exist (O3b, 2015). These concerns have largely been voiced in the form of petitions and complaints ignored or denied by the federal government (EchoStar, 2014; EchoStar and Hughes, 2017).

Much of the radio frequency spectrum is designated as either federal exclusive or federal primary, leaving a small portion for the commercial sector to utilize. Of this small portion, the co-primary frequencies allow the federal users to supplant the commercial. The commercial sector is clearly being treated unfairly, satellites in particular (de Selding, 2017). However, through interviews conducted for this study, it was found that the awareness of this issue amongst key stakeholders, including those in the academia and the federal government, is low. When asked about the existence of this issue, many of the interviewees responded that they were not aware. For example, one of the interviewee responded saying, “I am not surprised that such issue exists, but I have not heard anyone expressing it.” Furthermore, because every single license is granted by the organization to whom industry would complain, the current system discourages companies from complaining too loudly as it would hurt their future chances of receiving licensing. As such, it is difficult to find clear language on the problem in academic circles, let alone in the public sphere. The study finds that industry participants have a concern that is difficult to articulate because of fear of reprisal and thus difficult to address without a campaign led by a representative entity.

Therefore, this study recommends that the Satellite Industry Association begin a targeted awareness campaign to educate key stakeholders on the scope of the issue and how current regulations harm many of SIA's key constituents. Through the means of petitions, publications (news articles, scholarly journal articles, press releases, and so on), SIA could express this issue and its full scope, to both a broader audience as well as the ones most able to shape the future of how co-primary status is given and monitored to ensure fairness. The fact that a government policy is not being carried out as it is meant to be is a critical issue. Also, the Obama administration had emphasized its support of the commercial space industry and the importance of public-private partnerships (White House, 2014). Considering the pro-industry and pro-private sector characteristics of the Trump administration, the political environment is adequate to raise the awareness of this unfair public-private partnership practice.

Similarly, efforts towards lobbying should be made. The study recommends that SIA's Earth Observation Forum speak to members of the Energy and Commerce Committee and Senate Committee on Commerce Science and Transportation and encourage them to hold a hearing or otherwise push the issue of the co-primary fallacy to a higher forum. Closed-door events, which SIA has significant experience in holding and drawing congressional members to as speakers, would be another means of broaching the subject.

The commercial industry has consistently requested for more frequencies to be made available. Asking for reallocation of frequencies that are federal exclusive or primary has been proven to be a difficult task. To a certain degree, receiving equal treatment in the co-primary frequencies could have the same impact as receiving more frequency allocation. Also, such request would be accepted more favorably than asking for more frequency allocation, as this is the way the policy has been formulated from the very beginning.

Recommendation 2: Urge FCC to Adopt an Enhanced Licensing Regime

This study finds that FCC likely has the capability and resources to enhance its licensing system such that it incorporates the four dimensions of power, frequency, location, and timing of a satellite's transmissions to and from a terrestrial ground station. It acknowledges that tracking all four factors would be inoperably complex for most broadcasting systems, but the constant nature of a satellite's orbit coupled with the stationary nature of the ground station make for a much simpler modelling process. Therefore, it is recommended that the Satellite Industry Association's Earth Observation Forum adopt a unified platform of encouraging the FCC to adopt an enhanced licensing regime for satellite spectrum usage. The new policy would grant unused space and time in an already-allocated spectrum band to be used for new opportunities. The members of the Earth Observation Forum could seek further benefit if they wished by also advocating for the right to market 'timeshares' of spectrum already allocated to them to new entrants. Such an arrangement would be universally beneficial, as the new supply of spectrum would lower the barrier of opportunity to new uses of the good and the revenue from 'timesharing' spectrum would serve as a reward for the early innovators of satellite development (and a reminder of the financial windfall that may arise from taking the risk of opening up new markets).

Recommendation 3: Conduct Study of "Smart Spectrum" Benefits

While some research has been conducted regarding the advantages of dynamically allocating satellite spectrum through the technology used in short-range 'smart spectrum' systems, it is not yet developed enough technologically to support a shift in public policy. A report detailing the benefits of smart spectrum, potential dangers of inaction, and a path for accelerated development could give lawmakers and companies clearer incentives.

Such a report could come from the Congressional Research Service, or a prominent industry member with lobbying weight such as Boeing, and would serve as an excellent argument in favor of incorporating smart spectrum into the FCC's and NTIA's spectrum allocation procedures.

However, a report from the CRS must be requested by a particular category of individual. This study recommends that the members of SIA's Earth Observation Forum speak to one of the following legislators and encourage them to request a report from the CRS: Congressman Brett Guthrie (R-KY-2), who sponsored H.R. 1641 – Federal Spectrum Incentive Act last year, Senator Roger Wicker (R-MS), who chaired the hearing on spectrum early March 2017 at which SIA's own Mr. Tom Stroup spoke, and Congresswoman Doris Matsui (D-CA-6) who sponsored H.R. 4190 promoting innovative solutions for greater spectrum efficiency. Along with the Earth Observations Forum's established contacts, these members have demonstrated an interest in spectrum usage and policy. SIA and the EOF could also conduct research into the practicality of smart spectrum itself and publish the findings, but such publications might not carry as much weight across the policy spectrum since they will be coming from a biased party to the discussion.

Another option would be to host a public challenge to develop and demonstrate smart spectrum capabilities. DARPA is currently conducting the Spectrum Collaboration Challenge (SC2) for greater efficiency across all spectrum uses, but its Challenge could serve as the model for one organized by the interested members of the EOF. Hosting a public competition would require a significant commitment of resources but would have the added benefit of increasing public awareness outside the technical and policy community. These sorts of competitions make for good reading in popular magazines and can reach a wider audience than a publication specific to the field of spectrum coordination. Furthermore, the transparency of a competition will help produce trust in the results of the competition. It will be more difficult to condemn the viability of smart spectrum for satellite communication when it has been demonstrated under the public eye rather than entirely amongst industry advocates.

Recommendation 4: Encourage Development of Hub Satellite Concept

At present, there is little immediate action to be taken by SIA in pursuit of the 'hub' satellite concept. There are already two ventures pursuing some variation of the idea. Inmarsat and

Addvalue Innovation have concluded over a year of in-space tests of using a hub satellite to download and upload data between a cubesat and a ground station, going so far as to update the software of the cubesat via the hub during orbital operations. However, the current prospectus for the members of the Earth Observation Forum is unclear, as the tested system lacks the bandwidth to transmit Earth observation imagery effectively and Earth observation was explicitly stated to be a poor match by a representative of Inmarsat (SpaceNews; 2017). The other trailblazer is Audacy, who is not as far along in the development process, as it only submitted an application to the FCC in November of last year. However, it is pursuing the satellite hub concept aggressively with an operational target date in 2019. Furthermore, Audacy's target market includes the members of the Earth Observation Forum, as Audacy claims that with three satellites in differing medium Earth orbits (MEO) it can achieve constant coverage between a specific satellite and an associated ground station at all times. They also claim to have the bandwidth to support the quantity of data that Earth observation produces, although the actual download capability remains unannounced (Audacy; 2017). This study recommends that SIA and its members continue to follow the developments of these two companies and consider either the possibility of business arrangements with either, or incorporating the download hub concept into their own Earth observation operations.

Recommendation 5: Increase Efficiency of Spectrum Management of Federal Agencies

More of the frequency spectrum is allocated to the federal government than the non-federal sector. However, as discussed earlier, federal users of the spectrum have been criticized for "warehousing" the allocated spectrum. As inefficiency in spectrum management increases the level of scarcity of the limited resource, it is detrimental to the nation's ability to expand its space related capabilities and should be avoided to the best extent possible. In order to minimize the inefficiency in spectrum usage and management on the federal side, we recommend that SIA, along with other commercial space associations, advocate for a regulation to make federal users accountable and responsible for efficient uses of the spectrum.

Currently, these users do not have incentives to be efficient in their usage. NTIA allocates spectrum at no cost. Also, federal agencies do not receive any benefit for giving up the frequencies that they do not need. Therefore, frequencies that are not currently used by any federal entity stay vacant. These frequencies can otherwise be used or shared with the commercial industry. One possible regulation that would encourage the federal side to be more efficient with its use is to make agencies pay for spectrum allocation. If they have to pay for the frequencies they are allocated, these users will not let the frequencies go to waste. They would request to use only what they need, and the warehoused frequencies can be shared with the commercial industry.

Another possible regulation is to provide incentives for giving up frequencies that federal agencies do not use. To encourage participation in such a program, a federal agency which gives up its frequencies should be given favorable consideration when the agency requests additional frequency in the future. If there exists no assurance that frequencies will be available when they are needed, federal users would be better off warehousing them, as they do currently.

Conclusion

This study outlined current spectrum allocation policy, crucial capabilities provided by spectrum usage, and why an impending crisis in allocation of the spectrum in the face of unprecedented demand is a critical issue for the Satellite Industry Association (SIA), the U.S. satellite industry, and people around the world. The authors also defined the proportionally increasing difficulty of avoiding interference to signals due to rapid recent increases in usage and poor coordination by regulators. A discussion of the increasing scarcity of the spectrum and the intricacies of how competing interests of government, established companies, and new commercial players are coming ahead establishes why there is a crucial need for technical and procedural changes to the regulation and allocation of the radiocommunication frequency spectrum.

The study offered a series of potential technical and non-technical solutions, including multiple means of producing an enhanced licensing regime, as well multiple technologies that could drive better use and/or management of spectrum. The authors presented five recommendations for how SIA can drive the future of spectrum. Recommendations 1, 2, and 5 focus on non-technical means, while recommendations 3 and 4 rely on the development of new technologies to avert a potential crisis in the management of this key natural resource.

To reiterate, Recommendation 1 would give voice to those who might be punished for complaining about unfair treatment by licensing authorities. Recommendation 2 suggested changing how allocators choose to give out spectrum. Recommendation 3 focused on machine learning, i.e. removing the human element in management altogether, which would allow for fewer resources to be allocated on non-technical solutions over time. Recommendation 4 focused on limiting the use of spectrum by concentrating communications between the Earth and space assets to a single point, thereby limiting possible interference to the single point of communication. Finally, Recommendation 5 would involve incentives and repercussions to encourage federal users to act more responsibly and proactively on spectrum issues.

The National Space Policy of the previous administration had called for the federal government to encourage growth in commercial space sectors. The current administration has expressed its inclination for increased private-public partnership to build a robust space commercial economy. However, as seen with the ineffective spectrum allocation regime explained in this report, the regulations and policies that govern the playing field for commercial companies are not aligned with the directions of overarching national policies. This disconnect is not only present in the Earth Observation industry and spectrum allocation, but many other commercial space sectors, as well. The excess supply of spaceports compared to the launch demand, the excess supply of future launch providers compared to the future launch demand, the insufficient resource to support the future earth observation satellite licensing demand, and the absence of regulatory regime for small satellite constellation licensing and registration are few of the many examples where the push for the goal to foster space commercialization is not supported by the nation's operational level policies and regulations. In order for the United States to establish a sustainable commercial space sector, current ineffective and inefficient spectrum policies should be corrected.

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