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Overview of Department of Defense Use of the Electromagnetic Spectrum

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SUMMARY

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Overview of Department of Defense Use of the Electromagnetic Spectrum

Communication using the electromagnetic spectrum ("the spectrum") enables a number of modern military capabilities. The Department of Defense (DOD) uses electromagnetic radiation to enable military communications, navigation, radar, nonintrusive inspection of aircraft, and other equipment. DOD also heavily relies on electromagnetic radiation for intelligence, surveillance, and reconnaissance (ISR) applications such as missile early warning and signals intelligence. Individual branches of the military (e.g., the Air Force, Army, Marine Corps, Navy and Space Force) currently are allotted significant ranges of frequency bands to enable various equipment and applications that support military operations.

Potential adversaries like China and Russia have observed how the United States wages war through conflicts ranging from Desert Storm to Allied Force, Iraqi Freedom, and Enduring Freedom over the past 30 years. These potential adversaries have identified the DOD's use of the spectrum as a critical enabler, and, as a result, have developed weapon systems, particularly electronic warfare (EW) platforms, designed to challenge the DOD's ability to effectively use the spectrum. These technologies designed to deny access to the spectrum are part of a series of systems and technologies that are commonly referred to as anti-access/area denial capabilities. Several new and emerging technologies and methods to employ existing technologies (called concepts) are being developed to counter these challenges. These new technologies include directed energy, artificial intelligence, and counter-unmanned aircraft systems. Concepts like Joint All Domain Command and Control (JADC2) and Mosaic Warfare look to change the nature of how the DOD communicates and uses the spectrum.

The U.S. government manages access to and use of spectrum. As the nation continues to experience significant growth in commercial wireless services (e.g., mobile phones, mobile applications, video streaming, Wi-Fi), demand for spectrum has increased. Congress has enacted policies to make additional spectrum available for commercial use, in some cases reallocating spectrum from federal agency use to commercial use. As Congress considers policies that reallocate spectrum from DOD to commercial use, it may consider the following issues:

- **Interoperability** (i.e., the ability of one radio or computer system to talk to another). Each of the military services has developed robust networks of their own; however, many are often unable to communicate with one another.
- **DOD's ability to keep pace with technological advances by potential adversaries.** Adversaries such as Russia, China, Iran, and North Korea have developed systems to challenge the U.S. military's ability to access the spectrum and to reduce the effectiveness of future technologies.
- **The private sector's increasing interest in using frequencies traditionally reserved for the military.** The advent of fifth generation communications technologies (5G) has increased the demand for multiple different frequency bands, which has the potential to disrupt military operations. For example, in 2020 the Federal Communications Commission (FCC) authorized the Ligado 5G network, which could affect the global positioning system's radio signals.
- **Spectrum sharing.** Emerging technologies and policies are demonstrating that DOD and commercial systems are able to use the same frequencies without degrading DOD's capabilities. The process for identifying such potential spectrum-sharing frequencies and the ability to develop technologies quickly may also be of interest to Congress.

- **The interagency process for spectrum allocation.** Questions about the interagency process emerged after the FCC authorized Ligado's 5G network to operate, despite the fact that DOD and several other federal agencies disagreed with that decision.
- **Anticipating future spectrum needs for both commercial and military users.** Much attention has focused on 5G technologies. However, new technologies—like a future sixth generation (6G) of communications technologies—will increase demand for additional spectrum. Moreover, new military technologies may change how DOD uses the spectrum and may require a different spectrum allocation.

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The Department of Defense (DOD) is the largest federal user of the electromagnetic spectrum ("the spectrum"). It holds frequencies across multiple bands to support a number of technologies and uses. DOD utilizes spectrum on a day-to-day basis, for training, and for military operations. Thus, any changes to spectrum could affect DOD operations, both domestically and with allies abroad. Further, DOD has invested significantly in spectrum-dependent technologies. A summary of some of these technologies, including wireless communications, satellites, radar technologies that support situational awareness, signal intelligence and electronic warfare technologies, is provided below. Changes in spectrum may affect how DOD can use, manipulate, or develop these technologies.

The Department of Defense (DOD), partly through congressional action, has begun to re-prioritize its management and use of the spectrum. Since 2018, the DOD has created new organizational structures and is in the process of developing new strategies and policies, recognizing the importance the spectrum plays in military operations. A recent Joint Electromagnetic Spectrum Operations publication states:

> [t]he electromagnetic spectrum (EMS) is a maneuver space essential for facilitating control within the operational environment (OE) and impacts all portions of the OE and military operations ... Just as in the physical domains and in cyberspace, military forces maneuver and conduct operations within the EMS to achieve tactical, operational, and strategic advantage. Freedom of maneuver and action within the EMS are essential to US and multinational operations.[1]

What Is the Electromagnetic Spectrum?[2]

The electromagnetic spectrum is the range of wavelengths or frequencies of electromagnetic radiation. It includes radio waves, microwaves, visible light, X-rays, and gamma rays (see **Figure 1**). Electromagnetic radiation is all around us. It can be produced by natural sources, such as lightning or the sun, or by man-made sources, such as radio transmitters, microwave ovens, lasers, and X-ray machines. Electromagnetic radiation travels through space, air, and sometimes solid materials in the form of waves. These waves are called electromagnetic waves because they have both electric and magnetic properties. Such waves vary in frequency,[3] wavelength,[4] and energy. Scientists classify electromagnetic waves by their wavelength or frequency. Waves with shorter wavelengths (e.g., gamma rays) have higher frequencies and higher energy; waves with longer wavelengths (e.g., radio waves) have lower frequencies and lower energy.

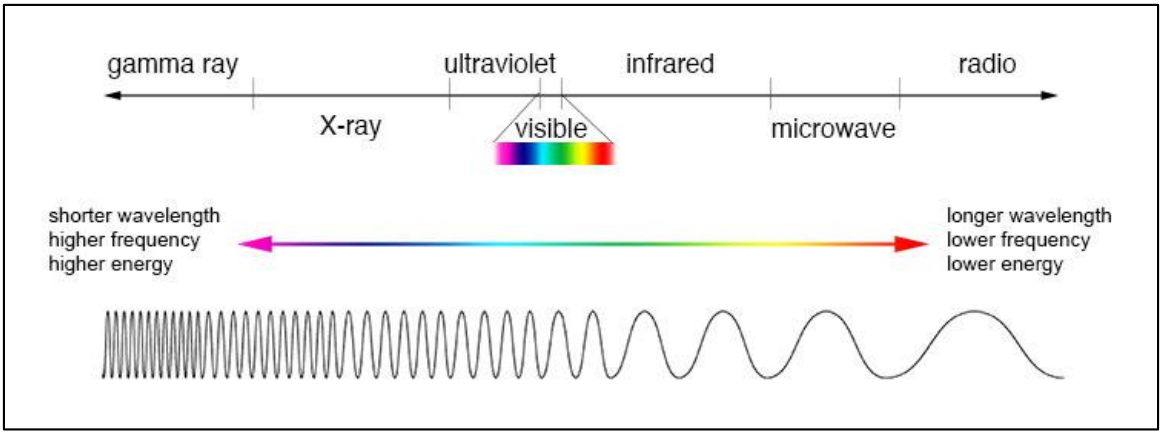
[1] Department of Defense, *Joint Electromagnetic Spectrum Operations*, JP 3-85, Washington, DC, March 22, 2020, p. v, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_85.pdf?ver=2020-04-09-140128-347.

[2] This section was written by John R. Hoehn. For more information, see CRS In Focus IF11155, *Defense Primer: Military Use of the Electromagnetic Spectrum*, by John R. Hoehn.

[3] Frequency is the property of a wave that describes how many wave patterns or cycles pass by in a period of time. Frequency is measured in Hertz (Hz). A wave with a frequency of 1 Hz means that one wave (peak-to-peak) passes by each second.

[4] Wavelength is the distance between adjacent peaks in a series of periodic waves.

Figure 1. The Electromagnetic Spectrum



Source: National Aeronautics and Space Administration, "The Electromagnetic Spectrum," 2020, https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html.

Scientists and engineers have discovered many practical uses for electromagnetic radiation. For example, mobile phones convert human voice and digital information into signals that can be transmitted by low frequency, low energy radio waves to enable wireless communications. Medical professionals use machines to focus high frequency, high energy gamma rays to kill cancerous cells. Thus, common technologies use electromagnetic radiation to enable a wide variety of uses. In applications across civil, commercial, and government sectors, the characteristics of the waves used often drive the use. Below are examples of electromagnetic radiation uses and applications.

- Radio frequency waves can be used to transmit messages between electronic devices. Radio waves have varying wavelengths and characteristics that affect how much, how far, and in what conditions data can be transmitted between a sender and a receiver. Some very low frequency radio waves can travel long distances, and can penetrate seawater, but cannot support high data rates. These waves are useful for communications with submarines. Other radio waves can travel a long distance and pass through solid objects, like buildings and trees, making them useful for mobile communications. Still other radio waves can travel short distances and cannot penetrate dense objects, but offer greater bandwidth and speed. These radio waves may be useful for high-data applications, such as downloading or streaming videos within a home or office.
- Microwaves have higher throughput—data upload and download rates—than radio waves and therefore are able to transmit more data. However, microwaves are more limited in range and can be disrupted by solid objects. Hence, microwaves are often used for point-to-point transmissions. Microwaves are also used in radars—systems that send out pulses of high frequency waves that reflect off an object and back to the source. This technology capitalizes on the fact that the waves cannot penetrate solid objects, and uses this characteristic to gauge time and distance to an object. Microwaves are also used in satellite communications, which experience few obstacles in their transmission path.
- Infrared radiation (IR) is used in household items such as remote controls. Remote controls shoot pulses of IR energy to a receiver in a TV, for example. The receiver converts the light signals to electrical signals, instructing

microprocessors to carry out commands.[5] Similarly, infrared lasers can be used for point-to-point communications over short distances to provide high-speed, reliable connections. Infrared signals can travel only short distances and can be blocked by obstacles.

- X-rays can penetrate optically opaque materials and are routinely used in aircraft maintenance to identify cracks in airframes. X-rays are high-energy, high-frequency ionizing radiation; they have enough energy to remove an electron from (ionize) an atom or molecule, which could lead to mutations in a human cell's DNA, and could lead to cancer.[6]
- Certain technologies can detect gamma rays—high-energy radiation—to help identify potential nuclear events. Similar to X-rays, gamma rays present biological risks.

Federal Spectrum Allocation

In the United States, the National Telecommunications and Information Administration (NTIA) and the Federal Communications Commission (FCC) jointly manage use of the radio spectrum (3 Hz to 300 GHz) to balance U.S. government interests, private interests, and the public good.[7] NTIA manages radio spectrum use by federal agencies,[8] while the FCC manages nonfederal use—that is, radio spectrum use of the private sector, including broadcasting, mobile communication use, commercial, industrial, personal uses, and state and local government uses.[9] Both agencies coordinate on frequency allocation and assignment, and in setting technical requirements to avoid interference.[10]

The *allocation* of radio spectrum involves designating certain frequency segments for specific uses, such as mobile communications, satellite, and TV broadcasting. The *assignment* of radio frequencies occurs after the spectrum has been allocated for a specific use. The FCC assigns frequencies and grants licenses to nonfederal users to use certain segments or certain frequencies.[11] The NTIA assigns frequencies to federal agencies, authorizing them to operate in a specific segment of the radio spectrum.[12] The two agencies coordinate on radio spectrum

[5] Jim Lucas, "What is Infrared," *Live Science*, February 27, 2019, https://www.livescience.com/50260-infrared-radiation.html.

[6] American Cancer Society, *What are x-rays and gamma rays?*, accessed February 26, 2019, https://www.cancer.org/cancer/cancer-causes/radiation-exposure/x-rays-gamma-rays/what-are-xrays-and-gamma-rays.html.

[7] The NTIA and FCC also represent U.S. interests at international forums, such as the World Radiocommunication Conference (WRC) that works to globalize and harmonize spectrum allocation to facilitate international communications. Thus, allocation decisions are also dependent on agreements, treaties, and regulations that drive international use of the spectrum. For more information, see NTIA, "Spectrum Sharing," accessed February 26, 2020, https://www.ntia.doc.gov/legacy/osmhome/EPS/openness/sp_rqmnts/sharing7.html.

[8] P.L. 102-538.

[9] 47 U.S.C. §303.

[10] Spectrum decisions are also driven by international decisions to coordinate spectrum use and facilitate global communications.

[11] The FCC also designates some bands for unlicensed use. These bands are open for users (e.g., medical device makers, Wi-Fi equipment makers) who agree to adhere to certain technical requirements so that their equipment does not interfere with other unlicensed uses or nearby licensed uses.

[12] NTIA, *Federal Government Spectrum Compendium*, Washington, DC, August 21, 2017, https://www.ntia.doc.gov/other-publication/2017/federal-government-spectrum-compendium.

allocation and reallocation as specified in a Memorandum of Understanding (MOU).[13] The MOU, which dates back to 1940,[14] establishes a framework for compliance with the statutory requirements and stipulates that the Chairman of the FCC and Assistant Secretary for Communications and Information (i.e., the lead administrator for the NTIA), shall meet biannually to conduct joint spectrum planning.

The NTIA uses the Interdepartment Radio Advisory Committee (IRAC) as an interagency radio spectrum coordination body which consists of technical representatives from many agencies.[15] The IRAC advises the NTIA on federal radio spectrum needs so that it can represent the interests of federal agencies in discussions with the FCC. The FCC engages with the NTIA on spectrum discussions when changes in allocation or use may affect federal agency activities. After allocation occurs, federal users obtain authorization from NTIA—usually referred to as a frequency assignment. The DOD Chief Information Officer participates in the IRAC. The DOD's participation is guided by department policy.[16]

Current Military Applications of the Spectrum[17]

Nearly every modern weapons system—such as those used by airplanes, satellites, tanks, ships, and radios—depends on the spectrum to function. The military uses applications across the electromagnetic spectrum to support communications, situational awareness, military operations, and emerging technologies. These applications range from using very low-frequency radio waves to communicate with submarines underwater, to microwaves for datalinks to connect weapons systems (e.g., aircraft, satellites, ground forces, ships). **Figure 2** shows various applications in the *radio* segment of the electromagnetic spectrum.[18]

[13] "Memorandum of Understanding Between the Federal Communications Commission and the National Telecommunications and Information Administration," signed on January 31, 2003 by Michael K. Powell, Chairman of the FCC and Nancy J. Victory, Assistant Secretary for Communications and Information, U.S. Department of Commerce, available at https://www.ntia.doc.gov/files/ntia/publications/fccntiamou_01312003.pdf.

[14] The MOU includes This MOU establishes a framework for compliance with the statutory requirements and stipulates that the Chairman of the FCC and Assistant Secretary for Communications and Information shall meet biannually to conduct joint spectrum planning.

[15] NTIA, "Interdepartment Radio Advisory Committee (IRAC)," accessed February 26, 2020, https://www.ntia.doc.gov/page/interdepartment-radio-advisory-committee-irac.

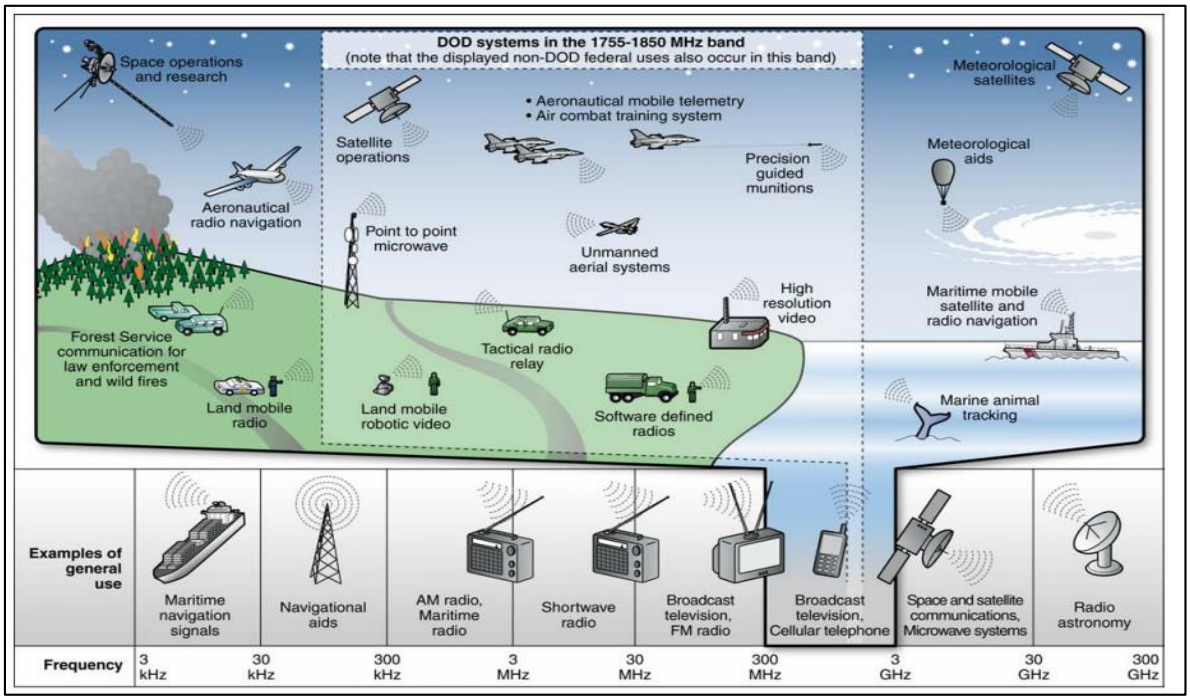
[16] Combined Communications-Electronics Board (CCEB), *Guide to Spectrum Management in Military Operations APC 190(C)*, September 2007, http://www.acqnotes.com/Attachments/ACP%20190(C)%20Guide%20to%20Spectrum%20Managing%20in%20Military%20Operations.pdf, and Thomas P. Kidd III, "Military Spectrum Management," Presentation, November 2019, http://ustti.org/wp-content/uploads/2019/11/Day-4-1_Military-Spectrum-Management_20180-0907.pdf.

[17] This section was written by John R. Hoehn. For more information on DOD spectrum operations, see CRS In Focus IF11155, *Defense Primer: Military Use of the Electromagnetic Spectrum*, by John R. Hoehn.

[18] The radio segment is typically described as those frequencies between 3 kilohertz (kHz) and 300 gigahertz (GHz). The highest frequency radio waves, from 300 megahertz (MHz) to 300 GHz, are called microwaves.

Figure 2. U.S. Department of Defense (DOD) Use of Radio Spectrum

Examples of DOD Systems Operating in the Radio Spectrum (3 kHz – 300 GHz)



Source: U.S. Government Accountability Office, *Spectrum Management: Federal Relocation Costs and Auction Revenues*, 13-472, May 2013, p. 6, https://www.gao.gov/assets/660/654794.pdf.

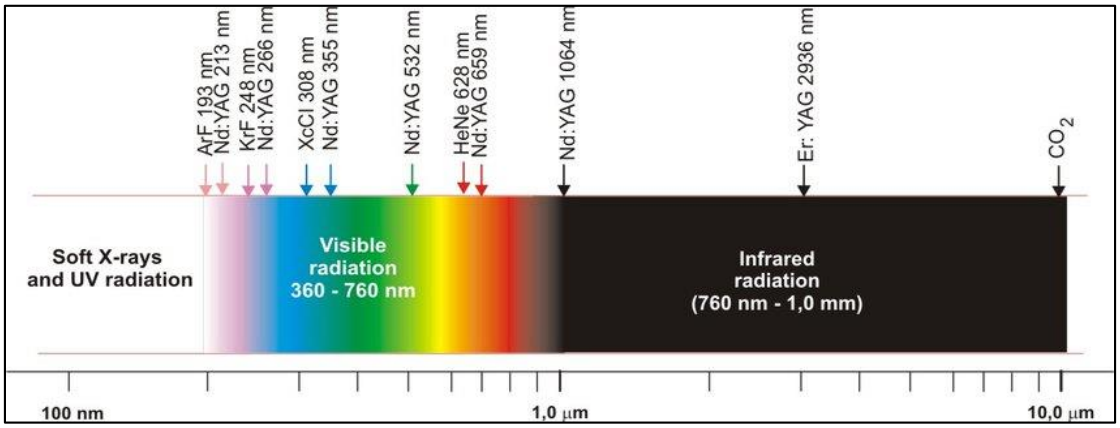
Notes: The figure shows allocated radio spectrum for DOD applications, with multiple uses operating in one band (1755-1850 MHz) and microwave systems in the upper bands (300 MHz-300 GHz).

Although the majority of military communications capabilities use radio waves and microwaves, the military also uses the infrared and ultraviolet spectrums for laser technologies and intelligence collection (see **Figure 3**). Infrared and ultraviolet lasers have greater bandwidth than radio frequencies, enabling the dissemination of large volumes of data (e.g., video) across long distances due to signal strength. The military can also use lasers offensively, to dazzle satellite sensors, destroy drones, and for other purposes.[19]

[19] Hemani Kaushal and Georges Kaddoum, "Applications of Lasers for Tactical Military Operations," *IEEE Access*, vol. 5 (September 22, 2017), pp. 20736-20753, doi: 10.1109/ACCESS.2017.2755678.

Figure 3. Spectrum Used for DOD Laser Technologies

Infrared and Ultraviolet Radiation Used for Laser Technologies



Source: Marczak, Jan & Andrzej, Koss & Targowski, Piotr & Michalina, GÃƒÂ³ra & Strzelec, Marek & Antoni, SarzyÃ…Â„ski & Wojciech, Skrzeczanowski & Ostrowski, Roman & Rycyk, Antoni. (2008). Characterization of Laser Cleaning of Artworks. Sensors. 8. 10.3390/s8106507.

These applications can be combined to provide an overall military capability, such as command and control (C2) or electronic warfare. The following discussion provides examples of DOD spectrum applications.

Communications

Military commanders have become accustomed to communicating with their forces nearly instantaneously. Commanders may use wired communications (e.g., landline phones, computers) or wireless technologies (e.g., radio systems)—technologies that use radio frequencies (spectrum) to transmit messages over-the-air between devices. Wireless communications are often used when there is no physical connection between the sender and receiver. The radio frequencies use range from low-bandwidth options, such as transferring small strings of text, to highly data-intensive applications, such as full motion video and video teleconferencing. The systems can be located terrestrially (either with ground forces or on ships), in the air, or in space (i.e., on satellites). In general, communications systems use radio and microwave frequencies; however, some emerging communications technologies use lasers—transmitting light, instead of radio waves, between receivers.[20] Radios use different frequencies depending on the required range and amount of data they are required to transmit. Ground-based radios are typically used at short ranges, limited by line of sight, that span no more than 50 miles. In general, militaries use satellites to communicate over longer distances.

Terrestrial Radios

For more than a century, the U.S. military has used ground-based (terrestrial) radios to communicate. In their infancy during World War I and World War II, these radios were used to transmit voice communications to coordinate forces. Radio systems have since evolved to use new frequency bands to transmit larger amounts of data. Systems like the Joint Tactical Radio

[20] Stephen Carlson, "Marines conduct field test of laser-based communications system," *UPI*, August 27, 2018, https://www.upi.com/Defense-News/2018/08/27/Marines-conduct-field-test-of-laser-based-communications-system/3511535389333/.

System (JTRS) provide new electronics to modulate the radio frequencies, enabling greater data transmission and encryption for security. Many of these terrestrial radios are limited to line-of-sight range due to the curvature of the earth. Some, like the PRC-117 Multiband Manpack Radio, use multiple frequency bands to transmit data—this radio system uses frequencies from 30 MHz – 2000 MHz.[21]

For several decades, the military has mostly used satellites to provide beyond-line-of-sight (BLOS) radio transmissions—signals traveling over the horizon, typically defined as extending no more than 50 miles. However, a few terrestrial-based systems can provide BLOS capabilities. An example is the AN/TRC-170 Tropospheric Scatter Microwave Radio Terminal (see **Figure 4**).[22] This radio uses microwaves to bounce signals off the troposphere, providing a BLOS capability for communications with ground forces at ranges of up to 100 nautical miles (approximately 115 standard miles), depending on weather conditions.

Figure 4. AN/TRC-170 Tropospheric Scatter Microwave Radio Terminal

Source: https://www.marines.mil/News/News-Display/Article/1169154/the-antrc-170-continues-to-stayreliable-for-the-corps/.

Notes: Photo by Lance Cpl. Cody Lemons.

Satellite Communications

Long-distance satellite communications range from data feeds for unmanned aircraft systems (also known as drones) to hardened signals for nuclear command, control, and communications.[23] Satellite communications generally use multiple frequency bands to transmit data more quickly. While satellite communications enables long–distance transmissions, it introduces latency (or time delay) because the transmissions must travel (at the speed of light) up and down to the satellite in orbit.[24] Most communications satellites operate in geosynchronous orbit (GEO), which

[21] L3Harris, "L3Harris Falcon III® AN/PRC-117G(V)1(C) Multiband Networking Manpack Radio," press release, 2020, https://www.harris.com/solution/harris-falcon-iii-an-prc-117gv1c-multiband-networking-manpack-radio.

[22] U.S. Marine Corps, "The AN/TRC-170 Continues to Stay Reliable for the Corps," press release, May 2, 2017, https://www.marines.mil/News/News-Display/Article/1169154/the-antrc-170-continues-to-stayreliable-for-the-corps/.

[23] These radio signals are designed to operate during a nuclear event, when most other electronic transmissions are disrupted.

[24] While there is a time delay when "drone" operators in the United States fly large unmanned aircraft in other parts of the world, this is augmented by automation and local ground control stations for critical phases of flight (i.e., takeoff landing, and taxiing) to reduce the effect of lag. Nuclear command and control uses multiple methods of communications—not just satellites—to issue orders to nuclear forces. This includes the E-4B National Airborne Operations Center and the E-6 Take Charge and Move Out systems.

is approximately 22,000 miles from the Earth's surface. This allows for satellite terminals to remain in position, rather than having to track a satellite in either low or middle earth orbits.

The U.S. military operates several global satellite communication constellations including

- Advanced Extremely High Frequency (AEHF),[25]
- Wideband Global Satellite Communications (WGS),[26] and
- Mobile User Objective System (MUOS).[27]

In addition to its own satellites, the DOD uses commercial satellites for communications. This is due, in part, to the limited bandwidth available on DOD-operated satellites (i.e., the number of satellites on orbit, the amount of data each satellite is able to transmit, as well as some limitations of coverage). Examples of satellite communications companies that contract with the DOD include Inmarsat, Viasat, Iridium, and Intelsat.[28]

Situational Awareness

Another defense application of the electromagnetic spectrum is the use of radio waves, microwaves, and infrared radiation to develop a picture of the battle space by determining the location of friendly and enemy forces. This is done through various technologies, as described below.

Radar and LIDAR

The most common situational awareness application is radar; however, recently light detection and ranging (LIDAR) systems are also used. Both technologies send out an electromagnetic signal and sense the portion that is reflected back to determine an object's distance, speed, and sometimes altitude. Radars operate on different radio and microwave frequencies, depending on their purpose. Lower-band frequency radars provide a longer range picture of the battle space, but because of clutter (undesired signals returned to the radar) they are not able to provide target-quality pictures. These systems are used for long-range surveillance, particularly for identifying ships and aircraft. Higher-band frequencies provide target-quality pictures, but lack the same effective range. Radar and LIDAR systems are commonly associated with air defense, military aviation, artillery, and space systems. While radar has become ubiquitous in military formations, LIDAR technologies are still being developed.

Passive Radar

Another technology that the U.S. and its competitors are developing is passive radar. Passive radars do not emit radio signals; instead, they listen to radio signals emitted from the target. Some

[25] For more information, see Air Force Space Command, "Advanced Extremely High Frequency System," fact sheet, March 22, 2017, https://www.afspc.af.mil/About-Us/Fact-Sheets/Display/Article/249024/advanced-extremely-high-frequency-system/.

[26] For more information, see U.S. Air Force, "Wideband Global SATCOM Satellite," fact sheet, November 15, 2015, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104512/wideband-global-satcom-satellite/.

[27] For more information, see Space and Naval Warfare Systems Command, "Mobile User Objective System (MUOS)," fact sheet, December 2011, https://www.secnav.navy.mil/rda/Documents/muos_overview_for_asn_rda_12-27-11-s.pdf.

[28] Sandra Erwin, "Satcom Conumdrum: Air Force Contemplating Right Mix of Commercial, Military Satellites," *SpaceNews*, May 6, 2019, https://spacenews.com/satcom-conumdrum-air-force-contemplating-right-mix-of-commercial-military-satellites/.

analysts argue that passive radars have the potential to detect low-observable aircraft such as the B-2 bomber and the F-35 fighter jet that are optimized for low radar cross section—the amount of measurable radar signal reflected back to its source—at certain frequencies and flight profiles (e.g., head on or the side).[29] Furthermore, because passive radars do not emit a signal, it is difficult to detect them using traditional methods (i.e., signals intelligence). Other analysts note that, while passive radars may aid in the detection of stealth systems, they do not necessarily provide the information needed to target and engage the systems and are therefore most useful as cues for other sensors.[30] Advances in microelectronics allow passive radar technology to detect different frequencies, such as cellular signals, that are traditionally not captured, enabling the potential detection of a wider range of aircraft. At the 2018 Berlin Airshow, a German radar company tested a newly developed passive radar to identify and track an F-35 using cellular frequencies among other techniques.[31] China and Russia have funded research and development efforts to further develop these technologies.[32] The DOD has funded research for this technology through the Defense Advanced Research Projects Agency (DARPA).[33]

Signals Intelligence

Signals intelligence (SIGINT) systems primarily detect and collect spectrum emissions. These passive systems—that is, they do not emit their own signal—can listen to radio and radar frequencies and observe heat signatures of personnel, missiles, aircraft, artillery, and vehicles. One subset of SIGINT is collecting communications signals to analyze how militaries communicate—such as what time radios transmit, from what location, and specific radio frequencies—as well as the data transmitted. A second subset of SIGINT is electronic intelligence. This intelligence discipline analyzes frequencies, patterns, operating procedures—among other information—of any other system that utilizes the spectrum. This includes radars, satellite systems, and signal jammers, among other systems.

Infrared Sensors

Hot objects emit radiation in the infrared segment of the spectrum. The higher their temperature relative to their surrounding environment, the easier they are to detect using infrared sensors. The U.S. military has long used infrared signatures to track enemy aircraft and ground vehicles and to guide missiles onto targets. The AIM-9X air-to-air and AGM-114 Hellfire air-to-ground missiles,

[29] Dimitrios Oikonomou, Panagiotis Nomikos, and George Limnaios, et al., "Passive Radars and their use on the Modern Battlefield," *Journal of Computations & Modelling*, vol. 9, no. 2 (2019), pp. 37-61.

[30] These analysts argue that passive radars typically use lower frequencies which do not provide a sufficient position to target a munition. Typical air defense radars use higher band frequencies to provide quality targeting data. Furthermore, the geometry to detect aircraft with passive radar systems can be extremely difficult, particularly if the source of the radio energy is not known. Tyler Rogoway, "No, Passive Radar Isn't Going to Make Stealth Technology Obsolete Anytime Soon," *The Drive*, September 30, 2019, https://www.thedrive.com/the-war-zone/30100/no-passive-radar-isnt-stealth-ending-magic-people.

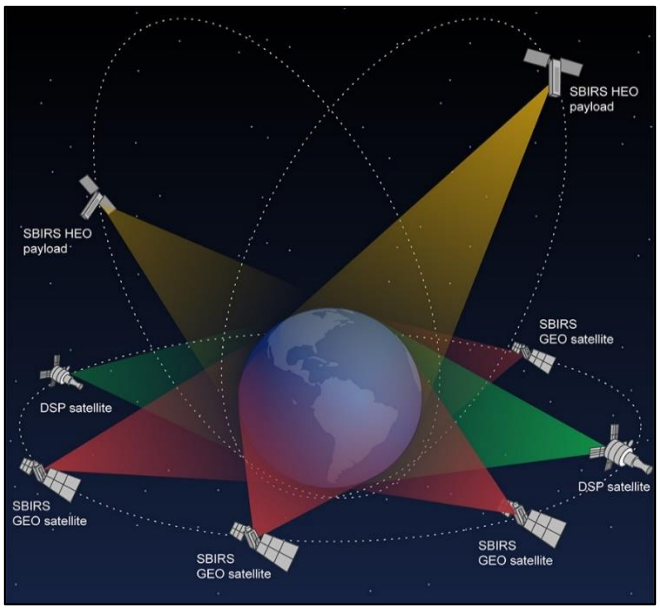
[31] Ibid. See also Sebastian Sprenger, "Stealthy No More? A German Radar Vendor Says It Tracked the F-35 Jet in 2018—from a Pony Farm," *C4ISRNet*, September 29, 2019, https://www.c4isrnet.com/intel-geoint/sensors/2019/09/30/stealthy-no-more-a-german-radar-vendor-says-it-tracked-the-f-35-jet-in-2018-from-a-pony-farm/.

[32] Gökhan Soysal and E.F.E. Murat, "UMTS passive radar implementation with two stage tracking algorithm," Communications Faculty of Sciences University of Ankara Series, 2016, pp. 29-53, https://dergipark.org.tr/en/download/article-file/778904.

[33] J.R. Wilson, "New frontiers in passive radar and sonar," *Military & Aerospace Electronics*, February 8, 2016, https://www.militaryaerospace.com/communications/article/16709052/new-frontiers-in-passive-radar-and-sonar. For more information on DARPA, see CRS Report R45088, *Defense Advanced Research Projects Agency: Overview and Issues for Congress*, by Marcy E. Gallo.

for example, use infrared guidance.[34] Aircraft use Infrared Search and Track (IRST) pods to identify enemy aircraft, particularly as advances in aircraft design embrace low radar cross-sections to make radar detection more difficult. The Navy is currently funding development of an IRST pod for the F-18E/F Super Hornet, and the Air Force has been procuring IRST capabilities for the F-15C Eagle.[35] Several space systems use infrared technologies to detect missile launches. The Space-Based Infrared Surveillance (SBIRS) constellation uses six satellites in geosynchronous orbit, as well as additional satellites in highly elliptical orbits (see **Figure 5**) to provide an early warning capability for missile launches.[36] The Space Force is developing a follow-on constellation for SBIRS. The Space Development Agency is developing a hypersonic missile detection constellation in low-earth orbit that would use infrared technologies similar to SBIRS.[37]

Figure 5. The Space-Based Infrared Surveillance (SBIRS) Constellation



Source: https://spacenews.com/air-force-tests-ground-station-for-full-missile-warning-constellation/.

Electronic Warfare

Electronic warfare (EW) is the use of the electromagnetic spectrum to gain and maintain military control of it.[38] SIGINT capabilities allow military forces to understand where adversary forces are

[34] U.S. Air Force, "AIM-9 Sidewinder," press release, December 18, 2004, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104557/aim-9-sidewinder/.

[35] U.S. Navy FY2021 Aircraft Procurement Line Item 0515 Infrared Search and Track (IRST), at https://apps.dtic.mil/procurement/Y2021/Navy/stamped/U_P40_0515_BSA-1_BA-5_APP-1506N_PB_2021.pdf, and U.S. Air Force FY2021 Aircraft Procurement Line Item F01500 F-15, at https://apps.dtic.mil/procurement/Y2021/AirForce/stamped/U_P40_F01500_BSA-2_BA-5_APP-3010F_PB_2021.pdf.

[36] Lockheed Martin, "Space Based Infrared Surveillance SBIRS," press release, 2020, at https://www.lockheedmartin.com/en-us/products/sbirs.html.

[37] Sandra Erwin, "Space Development Agency to Deploy Hypersonic Missile Defense Satellites by 2022," *Space News*, June 7, 2020, at https://spacenews.com/space-development-agency-to-deploy-hypersonic-missile-defense-satellites-by-2022/.

[38] Doctrinally, DOD changes the term from electronic warfare to electromagnetic warfare with the release of JP 3-85 in

located as well as what frequencies they use for communications and radars. This intelligence, which the military calls electronic support, is then used to develop an operational plan to jam (i.e., attack an adversary's use of the spectrum) radio frequencies. Testing SIGINT capabilities on their own forces, militaries can develop techniques to protect themselves from attacks.

Electronic warfare affects all military domains—land, air, sea, space, and cyberspace—and each of the military services has its own EW capabilities and programs. EW capabilities are traditionally divided into two distinct categories: terrestrial and airborne. Because each kind of EW has its respective advantages and disadvantages, multiple capabilities may be required to provide a desired effect. Terrestrial EW sensors and jammers—which can be located on land or on ships at sea—are limited by the amount of power available; these capabilities are also limited due to variance in the terrain in which they operate. Ground EW capabilities are used to intercept and to jam radios and artillery radars. Recent uses include jamming improvised explosive devices in Iraq and Afghanistan.[39] Airborne EW is used to intercept, decrypt, and disrupt communications, radars, and other C2 systems over a large area. Examples of airborne EW aircraft include the EA-18G Growler, and the EC-130H Compass Call.[40]

Spectrum Operations[41]

Numerous military operations use the spectrum, including command and control (C2), signature management, and navigation warfare. Overviews of these operations are discussed below.

Command and Control

One type of spectrum operation is Command and Control. C2 uses all of the above applications to develop a common operating picture (location of friendly and enemy forces) and communicate the commander's orders. Command and control is resourced according to a unit's size and mission focus, from a few radios and computers for platoon- and company-level operations to specialized satellites and aircraft for joint operations such as nuclear C2. Command and control aircraft, such as the E-8C Joint STARS, use communications systems and synthetic aperture radars to develop a comprehensive picture of the battlespace to direct ground forces to their most effective positions for countering enemy forces.[42]

Signature Management

Low observable weapons systems manipulate the spectrum to reduce their electromagnetic signature, such as radar returns,[43] radio emissions, and even heat. This signature management can

May 2020. However, Congress has traditionally used, and continues to use the term electronic warfare in legislation. For example P.L. 116-283. This report uses the term electronic warfare to conform with congressional and committee jurisdiction language. See CRS In Focus IF11118, *Defense Primer: Electronic Warfare*, by John R. Hoehn.

[39] For more information on ground electronic warfare systems see CRS Report R45919, *Ground Electronic Warfare: Background and Issues for Congress*, by John R. Hoehn.

[40] For more information about these aircraft systems see CRS Report R44572, *U.S. Airborne Electronic Attack Programs: Background and Issues for Congress*, by John R. Hoehn.

[41] This section was written by John R. Hoehn.

[42] U.S. Air Force, *E-8C Joint STARS*, Washington, DC, September 23, 2015, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104507/e-8c-joint-stars/.

[43] Radar works by emitting a radio signal and then listening for the signal to return. Low observable technologies use different materials (known as radar absorbing material) and different shapes (typically reducing the number of 90° or

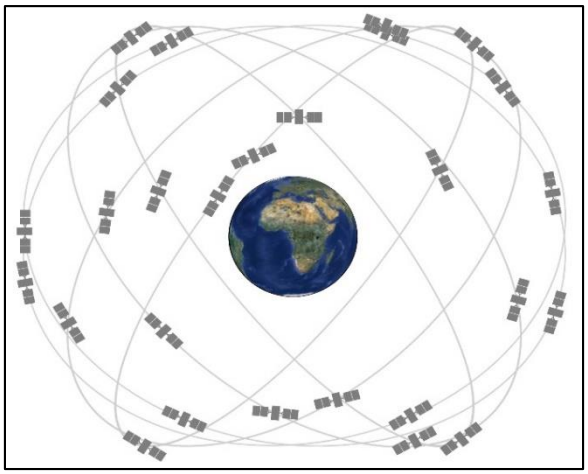
take many forms; for example, reducing a radar signature through physical or other means, creating narrow radio beams to reduce the probability of detection or intercept, and reducing spectrum emissions. These design approaches can be used in ships (e.g., Zumwalt-class destroyer), aircraft (e.g., the B-2 Spirit and the F-35 Lightning II), and radar systems (e.g., the AN/APG-81 actively electronically scanned array radar).[44] These systems look to reduce their signature in the microwave and infrared parts of the spectrum.

Communications systems are also focused on reducing their signature. Using beam-forming, reduced power, and other techniques, these systems are designed to be low probability of intercept/low probability of detection (LPI/LPD). The intent is to make it more difficult for potential adversaries to use their SIGINT capabilities to find U.S. forces, and potentially target them with long-range munitions.

Navigation Warfare

According to DOD, navigation warfare (NAVWAR) is "[d]eliberate offensive and defensive actions to assure friendly use and prevent adversary use of positioning, navigation, and timing information through coordinated employment of space, cyberspace, and EW capabilities. NAVWAR is further enabled by supporting activities such as ISR and EMS management."[45] The Global Positioning System (GPS) performs navigation warfare for the U.S. military by providing positioning, navigation, and timing (see **Figure 6**). Competing PNT systems have been developed by other nations, including Russia (GLONASS), China (Beidou), and the European Union (Galileo).[46]

Figure 6. The Global Positioning System (GPS) Constellation



Source: https://www.gps.gov/multimedia/images/constellation.jpg.

right angles) to reduce or prevent the radio signals from returning to their original source.

[44] For more information on select low observable aircraft, see CRS Report R44463, *Air Force B-21 Raider Long-Range Strike Bomber*, by Jeremiah Gertler, and CRS Report RL30563, *F-35 Joint Strike Fighter (JSF) Program*, by Jeremiah Gertler. For more information on the Zumwalt-class destroyer, see CRS Report RL32109, *Navy DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress*, by Ronald O'Rourke.

[45] Department of Defense, *DOD Dictionary of Military and Associated Terms*, January 2021, at: https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/dictionary.pdf.

[46] U.S. GPS Office, "Other Global Navigation Satellite Systems (GNSS)," press release, January 30, 2020, at https://www.gps.gov/systems/gnss/.

Command and Control (C2)

C2 systems are the communications, people, and procedures that enable commanders to direct forces. DOD states that communications systems are critical in providing timely information to enable decisionmaking.[47] According to DOD, these communications need to be interoperable (interoperability between communications systems revolves around the protocols such as frequency hopping and encryption, as well as the frequencies uses) to facilitate information sharing, agile to adjust to the operating environment, and trusted to ensure the information in the system is accurate. An important aspect of C2 systems is the ability to network and share information in a timely fashion to enable commanders and their staff to make decisions. Thus C2 systems collect information from intelligence systems and build a picture of the operating environment for the commander and their staff to make effective decisions (some analysts combine C2 with computers, communications, intelligence, surveillance, and reconnaissance systems [C4ISR] to talk about the entire system enabling decisionmaking). To create these networks, DOD utilizes computers to manage and process data and communications equipment so that commanders can act upon the data transmitted to them.

Emerging Military Applications of the Spectrum[48]

The following section discusses emerging technologies and concepts that could affect the military's use of the spectrum.

Fifth Generation (5G) Communications[49]

The fifth generation (5G) of mobile technologies will increase the speed of data transfer and improve bandwidth over existing fourth generation (4G) technologies, in turn potentially enabling new military and commercial applications. 5G technologies plan to use three segments of the electromagnetic spectrum: high band (also called millimeter wave, or MMW), which operates between around 24 and 300 gigahertz (GHz); mid band, which operates between 1 GHz and 6 GHz; and low band, which operates below 1 GHz. Mid band and low band are often collectively referred to as sub-6.[50] Each band offers different capabilities. High-band spectrum offers ultra-fast services to high-density areas but is limited in range and more vulnerable to disruption. Mid-band spectrum offers improved capacity and coverage, faster service, and new features (like edge computing) compared with existing 4G technologies. Low-band spectrum offers the widespread coverage needed for many internet-of-things applications.

5G technologies could have a number of potential military applications, particularly for autonomous vehicles, C2, logistics, maintenance, augmented and virtual reality, and intelligence, surveillance, and reconnaissance (ISR) systems—all of which would benefit from improved data

[47] Department of Defense, *Joint Communications System*, JP 6-0, Washington, DC, June 10, 2015, Incorporating Change 1, October 4, 2019, p. vii, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp6_0ch1.pdf?ver=2019-10-15-172254-827.

[48] This section was written by John R. Hoehn and Kelley M. Sayler.

[49] This section is derived from CRS In Focus IF11251, *National Security Implications of Fifth Generation (5G) Mobile Technologies*, by John R. Hoehn and Kelley M. Sayler. For more information on 5G, see CRS Report R45485, *Fifth-Generation (5G) Telecommunications Technologies: Issues for Congress*, by Jill C. Gallagher and Michael E. DeVine.

[50] For more information on 5G spectrum allocation, see CRS Report R45485, *Fifth-Generation (5G) Telecommunications Technologies: Issues for Congress*, by Jill C. Gallagher and Michael E. DeVine.

rates and lower latency (i.e., less time delay).[51] Autonomous military vehicles, like their commercial counterparts, could potentially circumvent on-board data processing limitations by storing large databases (e.g., maps) in the cloud. 5G technologies could also be incorporated into ISR systems, which increasingly demand high-bandwidths to process, exploit, and disseminate information from a growing number of battlespace sensors. Similarly, 5G could reduce latency in other data-intensive activities, such as logistics and maintenance, and could additionally enable augmented or virtual reality environments that could enhance training.[52] Finally, C2 systems could benefit from the high speed, low latency capability of 5G.[53]

DOD has expressed interest in developing 5G networks and technologies. DOD is in the initial stages of testing and experimentation for 5G applications. It has selected 12 military installations as test beds for various applications and aspects of the technology:

- Marine Corps Logistics Base Albany, GA (smart warehouses);
- Naval Base San Diego, CA (for smart warehouses);
- Hill Air Force Base, UT (spectrum sharing between 5G and airborne radar);
- Joint Base Lewis-McChord, WA (augmented and virtual reality);
- Nellis Air Force Base, NV (survivable command and control and network enhancement);
- Naval Base Norfolk, VA (ship-wide and pier connectivity);
- Joint Base Pearl Harbor-Hickam, HI (enhancing aircraft mission readiness);
- Joint Base San Antonio, TX (augmented reality support of maintenance and training and evaluating DOD's 5G core security experimentation network);
- Tinker Air Force Base, OK (spectrum sharing between military communications and 5G);
- Camp Pendleton, CA (connectivity for forward operating bases and tactical operations centers);
- Ft. Hood, TX (connectivity for forward operating bases and tactical operations centers); and
- Ft. Irwin National Training Center, CA (for connectivity for forward operating bases and tactical operations centers).[54]

On September 18, 2020, DOD released a Request for Information seeking input on best methods for sharing spectrum between military and civilian users, input on DOD ownership and operation of 5G networks for domestic operations, and other issues related to the allocation and shared use

[51] The U.S. military currently uses satellites for the preponderance of its long-distance communications; however, satellite communications can significantly increase latency due to the amount of distance a signal needs to travel, causing delays in the execution of military operations.

[52] Justin Doubleday, "DOD Releases Second Tranche of Draft 5G Proposal Requests," *Inside Defense*, December 9, 2019, https://insidedefense.com/insider/dod-releases-second-tranche-draft-5g-proposal-requests.

[53] Defense Innovation Board, *The 5G Ecosystem: Risks and Opportunities for DOD*, April 2019, https://media.defense.gov/2019/Apr/03/2002109302/-1/-1/0/DIB_5G_STUDY_04.03.19.PDF.

[54] Justin Doubleday, "DOD Releases Second Tranche of Draft 5G Proposal Requests," *Inside Defense*, December 9, 2019, https://insidedefense.com/insider/dod-releases-second-tranche-draft-5g-proposal-requests; and Department of Defense, "DOD Names Seven Installations as Sites for Second Round of 5G Technology Testing, Experimentation," press release, June 3, 2020, https://www.defense.gov/Newsroom/Releases/Release/Article/2206761/dod-names-seven-installations-as-sites-for-second-round-of-5g-technology-testin/.

of DOD spectrum.[55] The intent, DOD says, is to "ensure the greatest effective and efficient use of the Department of Defense's spectrum for training, readiness, and lethality."[56] DOD requested $1.5 billion for microelectronics/5G in FY2021, but it did not provide a further breakdown in funding between microelectronics and 5G.[57]

Use and Applications of Artificial Intelligence (AI)[58]

DOD is researching cognitive electronic warfare systems that use artificial intelligence to identify novel electronic emissions, determine whether the emission originates from a hostile source, and develop an effective jamming signal. According to former DOD electronic warfare official William Conley, "a future battlespace will contain threat signals not previously observed, [so] it will be essential for many platforms to be executing real time decision algorithms."[59] DOD is also researching options for using advances in computing power to improve electronic deception, or "spoofing," capabilities. For example, Digital Radio Frequency Memory could be used to generate false radar returns that complicate adversary targeting.[60]

Similarly, DOD is exploring AI-enabled dynamic spectrum sharing. Because spectrum is currently allocated in set segments, allocation cannot be responsive to changes in the volume of traffic across segments (i.e., some segments may be overwhelmed while others are underutilized), leading to inefficiencies. DARPA has sponsored the Spectrum Collaboration Challenge (SC2), which "aims to ensure that the exponentially growing number of military and civilian wireless devices will have full access to the increasingly crowded electromagnetic spectrum."[61] Teams competing in SC2—the final competition was held in October 2019—leveraged AI and machine learning algorithms to develop options for dynamic spectrum sharing, in which radios autonomously coordinate to optimize spectrum use.

Directed-Energy (DE) Technologies

A number of directed energy technologies, including laser communications and directed-energy weapons, make use of the electromagnetic spectrum.[62]

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[55] DOD, Request for Information, *Defense Spectrum Sharing Request for Information*, Published September 18, 2020, https://beta.sam.gov/opp/4851a65e2b2d4d73865a0e9865b0c28a/view?keywords=spectrum&sort=-modifiedDate&index=&is_active=true&page=1.

[56] Ibid.

[57] DOD *FY2021 Defense Budget Overview: Irreversible Implementation of the National Defense Strategy*, Washington, DC, May 13, 2020, pp. 1-8, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/fy2021_Budget_Request_Overview_Book.pdf.

[58] For a general discussion of military applications of artificial intelligence, see CRS Report R45178, *Artificial Intelligence and National Security*, by Kelley M. Sayler.

[59] "EW, Cyber Require Next-Gen Hardware: Conley," *Breaking Defense*, September 27, 2019, https://breakingdefense.com/2019/09/ew-cyber-require-next-gen-hardware-conley/.

[60] Ibid.

[61] DARPA, "Spectrum Collaboration Challenge (SC2)," https://www.darpa.mil/program/spectrum-collaboration-challenge.

[62] Other directed energy technologies include laser range finders, target designators, and remote sensors.

Laser Communications[63]

DOD is currently experimenting with several laser communications systems to improve communication data rates and to reduce the potential for adversaries to interfere (or jam) with DOD communications. One application for laser communications DOD is testing systems is for ground-based communications. This application uses focused infrared energy to transmit data. For example, Free Space Optics (FSO) "is an optical communication system that transfers data on a highly secured and nearly undetectable infrared laser, separate from the radio frequency spectrum…. This allows more users on a single network and larger files, imagery, and information to be transmitted."[64] The Marine Corps requested procurement funding for FSO in FY2019 and FY2020; however, it does not appear have requested funds in FY2021. It is unclear how many FSO systems the Marine Corps procured (see **Figure 7**).

Figure 7. U.S. Marine Corps Free Space Optics Communications System

Source: https://www.upi.com/Defense-News/2018/08/27/Marines-conduct-field-test-of-laser-based-communications-system/3511535389333/.

Notes: The picture caption reads: "U.S. Marines test the Free Space Optics laser communications system earlier this month at Camp Hansen in Okinawa, Japan. Photo by Sgt. Timothy Valero/U.S. Marine Corps."

Another application of laser communications is to relay data from one satellite to another (i.e., inter-satellite communications or space-to-space communications). Space laser communications rely on a large network of satellites operating in low earth orbit (LEO). Unlike radio frequencies, lasers have a narrow linewidth—the beam that facilitates communication—which significantly decreases the risk of signal jamming or disruption during point-to-point satellite communications.[65] Additionally, point-to-point laser communications provide a "straight line" path for data transfer. Laser communications in space do not rely on physical connections, such as fiberoptic cables,[66] thereby decreasing latency and potentially providing faster data rates. Indeed, communications lasers can potentially transmit 10 to 100 times more data than radio

[63] This section was written by John R. Hoehn and Katherine Leahy.

[64] Department of Defense, "Okinawa Marines Test Future of Wireless Communications," press release, August 24, 2018, at https://www.defense.gov/Explore/News/Article/Article/1611671/okinawa-marines-test-future-of-wireless-communications/.

[65] Lisbeth Perez, "DoD Pioneering NextGen Satellites, Sensors in Space," *MeriTalk,* June 23, 2021, https://www.meritalk.com/articles/dod-pioneering-nextgen-satellites-sensors-in-space/.

[66] Doug Mohney, "Space Lasers, Smart Antennas Are Key Enablers for Satellite Broadband," *Data Center Frontier,* March 3, 2021, https://datacenterfrontier.com/space-lasers-smart-antennas-are-key-enablers-for-satellite-broadband/.

frequencies,[67] increasing both capacity and speed.[68] To achieve a web of information sharing, a large group of satellites must be launched into LEO in order to ensure that ground-based terminals are in constant contact with a satellite.

The Space Development Agency (SDA), Defense Advanced Research Projects Agency (DARPA), Space Force, and Air Force Research Labs are interested in developing space-based laser communications technologies. Commercial companies, including Google, Facebook, and SpaceX, have also discussed the advantages of the high data rates and security offered by space laser communication.[69] On June 30, 2021 SpaceX launched the Transporter-2 Falcon 9 following the launch of the Transporter-1 on January 24, 2021.[70] These launches were considered rideshare missions, meaning that each rocket contained both commercial and government satellites. Additionally, the Space Development Agency plans to launch 150 satellites for laser communications into LEO by September 2024.[71]

Directed-Energy Weapons[72]

DOD defines directed-energy (DE) weapons as those using concentrated electromagnetic energy, rather than kinetic energy, to "incapacitate, damage, disable, or destroy enemy equipment, facilities, and/or personnel."[73] DE weapons could be used by ground forces in counter rocket,[74] artillery, and mortar (C-RAM), counter-unmanned aircraft systems (C-UAS), or short-range air defense (SHORAD) missions.[75] They could offer low costs per shot and—assuming access to a sufficient power supply—nearly limitless magazines that, in contrast to existing conventional systems, could enable an efficient and effective means of defending against missile salvos or swarms of unmanned systems.[76] Theoretically, DE weapons could also provide options for boost-

[67] These proposed data rates are because laser communications systems use higher frequencies in the infrared and potentially ultraviolet bands of the spectrum, as well as the elimination of weather and other atmospheric conditions.

[68] National Aeronautics and Space Agency, "Laser Communications: Empowering More Data Than Ever Before," press release, May 12, 2021, https://www.nasa.gov/feature/goddard/2021/laser-communications-empowering-more-data-than-ever-before.

[69] Patrick Tucker, "Space Lasers Will Revolutionize Military Communications, If They Work," *Defense One*, February 18, 2021, https://www.defenseone.com/technology/2021/02/space-lasers-will-revolutionize-military-communications-if-they-work/172134/, and Sandra Erwin, "DoD space agency to launch laser communications experiments on SpaceX rideshare," *Space News*, June 2, 2021, https://spacenews.com/dod-space-agency-to-launch-laser-communications-experiments-on-spacex-rideshare/.

[70] Sandra Erwin, "DoD space agency to launch laser communications experiments on SpaceX rideshare," *Space News*, June 2, 2021, https://spacenews.com/dod-space-agency-to-launch-laser-communications-experiments-on-spacex-rideshare/.

[71] Patrick Tucker, "Space Lasers Will Revolutionize Military Communications, If They Work," *Defense One*, February 18, 2021, https://www.defenseone.com/technology/2021/02/space-lasers-will-revolutionize-military-communications-if-they-work/172134/.

[72] This section is derived from CRS Report R46458, *Emerging Military Technologies: Background and Issues for Congress*, by Kelley M. Sayler.

[73] Joint Chiefs of Staff, Electronic Warfare, Joint Publication 3-13.1, February 8, 2012, pp. 1-16.

[74] For example, see CRS Report R45098, *U.S. Army Weapons-Related Directed Energy (DE) Programs: Background and Potential Issues for Congress*, by Andrew Feickert.

[75] For more information about the role of DE weapons in C-UAS missions, see CRS In Focus IF11426, *Department of Defense Counter-Unmanned Aircraft Systems*, by John R. Hoehn and Kelley M. Sayler.

[76] Although research has been conducted on chemically fueled lasers, most countries are now pursuing solid state lasers, which are fueled by electrical power. As a result, the cost per shot is equivalent to the cost of the electrical power required to fire the shot. Some analysts have noted that the cost per shot could thus be between $1 and $20. See Ariel Robinson, "Directed Energy Weapons: Will They Ever Be Ready?," *National Defense*, July 1, 2015, at

phase missile intercept, given their speed-of-light travel time; however, as in the case of hypersonic missile defense, experts disagree on the affordability, technological feasibility, and utility of this application.[77]

High-powered microwave weapons, a subset of DE weapons, could be used as a nonkinetic means of disabling electronics, communications systems, and improvised explosive devices, or as a nonlethal "heat ray" system for crowd control.

Although the United States has been researching directed energy since the 1960s, some experts have observed that "actual directed-energy programs … have frequently fallen short of expectations," with DOD investing billions of dollars in programs that were ultimately cancelled.[78] Others contend that developments in commercial lasers could be leveraged for military applications.[79] Directed-energy weapons programs, however, continue to raise questions about their technological maturity, including questions about their ability to improve beam quality and control to militarily useful levels and their ability to meet power, cooling, and size requirements so that the weapons could be integrated into current platforms.[80]

The U.S. Navy fielded the first operational U.S. DE weapon,[81] the Laser Weapon System (LaWS), in 2014 aboard the USS *Ponce*. LaWS was a 30-kilowatt (-kW) laser prototype that "was capable of blinding enemy forces as a warning, shooting down drones, disabling boats, or damaging helicopters."[82] The Navy plans to deploy its 60-kW laser, HELIOS, aboard the USS *Preble* in 2021, while the Army plans to field its first "combat relevant" laser—the 50-kW Directed Energy Mobile Short-Range Air Defense System—on Stryker fighting vehicles in FY2022.[83] Similarly, the Air Force is currently conducting field assessments of several counter-UAS DE systems, including both laser and high-powered microwave systems.[84]

The Army, Navy, Air Force, and DARPA each have additional DE development programs underway, with the Pentagon requesting $235 million for directed-energy weapons and directed-

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https://www.nationaldefensemagazine.org/articles/2015/7/1/2015july-directed-energy-weapons-will-they-ever-be-ready.

[77] See, for example, James N. Miller and Frank A. Rose, "Bad Idea: Space-Based Interceptors and Space-Based Directed Energy Systems," Center for Strategic and International Studies, December 13, 2018, at https://defense360.csis.org/bad-idea-space-based-interceptors-and-space-based-directed-energy-systems/; and Justin Doubleday, "Pentagon punts MDA's laser ambitions, shifts funding toward OSD-led 'laser scaling,'" *Inside Defense*, February 19, 2020, at https://insidedefense.com/daily-news/pentagon-punts-mdas-laser-ambitions-shifts-funding-toward-osd-led-laser-scaling.

[78] Paul Scharre, Preface to "Directed-Energy Weapons: Promise and Prospects," Center for a New American Security, April 2015, p. 4.

[79] See Ariel Robinson, "Directed Energy Weapons."

[80] Ibid.

[81] For more information see, CRS Report R44175, *Navy Lasers, Railgun, and Gun-Launched Guided Projectile: Background and Issues for Congress*, by Ronald O'Rourke.

[82] Kyle Mizokami, "The U.S. Army Plans To Field the Most Powerful Laser Weapon Yet," *Popular Mechanics*, August 7, 2019.

[83] Lockheed Martin, "Lockheed Martin's HELIOS Laser Weapon System Takes Step Toward Ship Integration," March 11, 2020, at https://news.lockheedmartin.com/2020-03-11-Lockheed-Martins-HELIOS-Laser-Weapon-System-Takes-Step-Toward-Ship-Integration; and Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer, "Defense Budget Overview: United States Department of Defense Fiscal Year 2021 Budget Request," February 2020, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/fy2021_Budget_Request_Overview_Book.pdf.

[84] Kyle Mizokami, "The Air Force Mobilizes Its Laser and Microwave Weapons Abroad," *Popular Mechanics*, April 9, 2020, at https://www.popularmechanics.com/military/weapons/a32083799/laser-microwave-weapons/.

energy defensive capabilities in FY2020; the FY2021 budget overview does not provide the topline funding request for DE weapons.[85] These programs are intended to scale up power levels from around 150 kW, as is currently feasible, to around 300 kW, a level at which cruise missiles could potentially be intercepted, by FY2022 and to around 500 kW by FY2024.[86]

Counter-Unmanned Aircraft Systems (C-UAS)[87]

Unmanned aircraft systems (UAS), commonly called drones, have proliferated rapidly and are available to nation states and to non-state actors and individuals. These systems could provide U.S. adversaries with a low-cost means of conducting intelligence, surveillance, and reconnaissance missions against—or attacking—U.S. forces. Furthermore, many smaller UASs cannot be detected by traditional air defense systems due to their size, construction material, and flight altitude.

C-UAS can employ a number of methods to detect the presence of hostile or unauthorized UAS. The first is using electro-optical, infrared, or acoustic sensors to detect a target by its visual, heat, or sound signatures, respectively. A second method is to use radar systems. However, these methods are not always capable of detecting small UAS due to the limited signatures and size of such UAS. A third method is identifying the wireless signals used to control the UAS, commonly using radio frequency sensors. These methods can be—and often are—combined to provide a more effective, layered detection capability.

Once detected, the UAS may be engaged or disabled. Electronic warfare "jamming" can interfere with a UAS's communications link to its operator. Jamming devices can be as light as 5 to 10 pounds and therefore man-portable, or as heavy as several hundred pounds and in fixed locations or mounted on vehicles. In addition, UAS can be neutralized or destroyed using guns, nets, directed energy, traditional air defense systems, or even trained animals such as eagles. DOD is developing and procuring a number of different C-UAS technologies to try to ensure a robust defensive capability.

In December 2019, DOD streamlined its various counter-small UAS (C-sUAS) programs, naming the Army as the executive agent tasked with overseeing all DOD C-sUAS development efforts. On January 6, 2020, the Secretary of Defense approved the implementation plan of the new office, known as the Joint C-sUAS Office (JCO). Working in consultation with the combatant commands and the Office of the Under Secretary of Defense for Acquisition and Sustainment, JCO assessed over 40 fielded C-sUAS systems. On June 25, 2020, Maj. Gen. Sean Gainey, director of the JCO, announced that seven C-sUAS defensive systems and one standardized command and control system are to be further developed. According to media reports, during its

[85] Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer, Defense Budget Overview: United States Department of Defense Fiscal Year 2020 Budget Request, March 2019, p. 9.

[86] Despite a lack of consensus regarding the precise power level needed to neutralize different target sets, it is generally believed that a laser of around 100 kW could engage UAVs, small boats, rockets, artillery, and mortar, whereas a laser of around 300 kW laser could additionally engage cruise missiles flying in certain profiles (i.e., flying across—rather than at—the laser). See, for example, CRS Report R41526, *Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress*, by Ronald O'Rourke, and Sydney J. Freedberg Jr., "Lasers to Kill Cruise Missiles Sought by Navy, Air Force, Army," *Breaking Defense*, October 29, 2019. For information about DOD's Laser Scaling Plan, see Jason Sherman, "New Laser Scaling Plan sets directed-energy efforts, FY-19 contracts," *Inside Defense*, April 17, 2019, at https://insidedefense.com/daily-news/new-laser-scaling-plan-sets-directed-energy-efforts-fy-19-contracts.

[87] This section is derived from CRS In Focus IF11426, *Department of Defense Counter-Unmanned Aircraft Systems*, by John R. Hoehn and Kelley M. Sayler.

first year of operation, the office is to additionally produce a DOD Directive on C-sUAS, a threat assessment of C-sUAS capabilities, a DOD C-sUAS strategy, and a Joint Capability Development Document outlining operational requirements for future systems.[88]

Emerging Concepts[89]

DOD is developing a series of concepts, many of which are enabled by AI, to improve multi-domain command and control (C2) and execute the National Defense Strategy. For example, DOD is developing a concept, Joint All Domain Command and Control (JADC2), to direct forces across multiple domains (air, space, cyber, land, sea).[90] According to defense officials, commanders currently execute C2 by exchanging data through manpower-intensive processes that typically focus on a single domain. This reduces a commander's situational awareness, speed of decisionmaking, and ability to rapidly and continuously integrate capabilities across domains. These processes are not automated and typically provide single domain awareness.[91] In contrast, JADC2 is to enhance information-sharing across domains through "a combination of new technology, processes and new organizations."[92]

Figure 8. Visualization of JADC2 Vision

Source: https://www.monch.com/mpg/news/ew-c4i-channel/7334-saic-and-usaf-partner-for-jadc2.html.

[88] Theresa Hitchens, "DoD Winnowing Efforts To Counter Small Drones," *Breaking Defense*, March 5, 2020, at https://breakingdefense.com/2020/03/dod-winnowing-efforts-to-counter-small-drones/.

[89] This section was written by John R. Hoehn, Kelley M. Sayler, and Nishawn S. Smagh.

[90] For more information about JADC2, see CRS In Focus IF11493, *Joint All-Domain Command and Control (JADC2)*, by John R. Hoehn.

[91] For example, the Air Force fields the Air Operations Center which provides command and control of air and space operations for a single combatant command. Similarly the Navy uses the Maritime Operations Center to command naval forces in a specific area of operation. For the Air Operations Center to share information (and potentially tasking instructions) with the Maritime Operations Center requires manual processes. Similarly these command and control structures are geographically focused, and do not provide insights into potential adversary operations in other geographic regions.

[92] Jay Koester, "JADC2 'Experiment 2' provides looking glass into future experimentation," *U.S. Army*, April 23, 2020, at https://www.army.mil/article/234900/ jadc2_experiment_2_provides_looking_glass_into_future_experimentation.

DOD uses ride-sharing service Uber as an analogy to describe its desired end state for JADC2. Uber combines two different apps—one for riders and a second for drivers.[93] Using the respective users' position, the Uber algorithm determines the optimal match based on distance, travel time, and passengers (among other variables). The application then seamlessly provides directions for the driver to follow, delivering the passenger to their destination. Uber relies on cellular and Wi-Fi networks to transmit data to match riders and provide driving instructions. The military equivalent might be using all available intelligence sensors—particularly space, air and maritime-based sensors—to detect adversary targets. Artificial intelligence algorithms would then identify where different missiles, aircraft, and artillery units are to determine the best to assign to an emerging target. Finally, using the optimal communications method the algorithms would then direct the appropriate munition onto the target. The Air Force has been designated as the executive agent charged with overseeing the services' first-year JADC2 activities.[94] JADC2 is intended to reach full operational capability by 2035.[95]

Similarly, DARPA has researched a concept called "Mosaic Warfare," intended to leverage AI to network systems and sensors, prioritize incoming sensor data, and autonomously determine the optimal composition of forces. Such concepts could provide a comprehensive common operating picture, coordinate operations across warfare domains, and challenge adversaries' targeting calculations. These concepts additionally propose limiting the amount of and/or disguising electronic emissions in the spectrum to further complicate adversaries' ability to target U.S. forces.

DOD Spectrum Strategies and Policies[96]

DOD has recently changed its strategy and organizational structure for and focus on spectrum operations. First, in May 2020, the Joint Staff released Joint Publication (JP) 3-85, which documents DOD's doctrine for Joint Electromagnetic Spectrum Operations.[97] This document states that the electromagnetic spectrum "is a maneuver space essential for facilitating control within the operational environment (OE) and impacts all portions of the OE and military operations."[98] JP 3-85 also changed how DOD trains and organizes for EMSO by combining electronic warfare and spectrum management operations into a single function. Previously, spectrum management and electronic warfare were two separate disciplines run by different organizations within each military command.[99] JP 3-85 notes that, while signals intelligence supports EMSO, it remains an intelligence discipline tasked by the intelligence directorate.

[93] Gen David Goldfein and Gen John Raymond, "America's future battle network is key to multidomain defense," *Defense News*, February 27, 2020, at https://www.defensenews.com/opinion/commentary/2020/02/27/americas-future-battle-network-is-key-to-multidomain-defense/.

[94] The services have a number of related programs that are designed to demonstrate the capabilities needed to execute JADC2, including the Army's Project Convergence and the Air Force's Advanced Battle Management System. Jay Koester, "JADC2 'Experiment 2' provides looking glass into future experimentation," *U.S. Army*, April 23, 2020, at https://www.army.mil/article/234900/jadc2_experiment_2_provides_looking_glass_into_future_experimentation.

[95] Ibid.

[96] This section was written by John R. Hoehn.

[97] Department of Defense, Joint Electromagnetic Spectrum Operations, JP 3-85, Washington, DC, May 22, 2020, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_85.pdf?ver=2020-04-09-140128-347.

[98] Ibid., p. I-1.

[99] Traditionally electronic warfare was managed by the operations directorate, while spectrum management was delegated to the communications directorate—this is akin to the Chief Operations Officer and Chief Information Officer in the commercial sector controlling different aspects and viewpoints of the spectrum environment. JP 3-85

Then, in September 2020, DOD released a new electromagnetic spectrum enterprise directive to set policy and assign bureaucratic responsibilities for EMSO.[100] This directive identifies the DOD Chief Information Officer (CIO) as the primary staff assistant for spectrum management policy, and the Undersecretary of Defense for Acquisition and Sustainment as the lead organization for electronic warfare programs.[101] The Undersecretary of Defense for Research and Engineering is designated as the primary organization responsible for developing spectrum management and electronic warfare technologies.

In October 2020, DOD released the *Electromagnetic Spectrum Superiority Strategy*.[102] The strategy outlines DOD's intent to "develop superior EMS capabilities; evolve to an agile, fully integrated EMS infrastructure; pursue total force EMS readiness; secure enduring partnerships for EMS advantage; and establish effective EMS governance to support strategic and operational objectives."[103] This strategy combines the DOD's electromagnetic spectrum strategy from 2013 and the electronic warfare strategy from 2017. The 2013 strategy identified the commercial sector's increasing demand for spectrum, which DOD calls "congestion."[104] The 2017 strategy identified how potential adversaries are developing systems to challenge U.S. dominance of the spectrum, which DOD terms "contested."[105] The new 2020 strategy combines these two approaches into a single document and outlines how DOD plans to meet commercial demand for spectrum, while being able to support operations in a contested environment. In addition, DOD is developing a roadmap and implementation plan to achieve the strategy's vision and goals.

From an operational perspective, U.S. Strategic Command traditionally has been delegated responsibility for the spectrum. The FY2021 National Defense Authorization Act (NDAA) directed that "the Secretary of Defense shall transfer to an appropriate entity within the Department of Defense all the responsibilities and functions of the Commander of the United States Strategic Command that are germane to electromagnetic spectrum operations" within two years.[106]

Potential Spectrum Issues for Congress[107]

As Congress considers several policy implications of the use of the spectrum, several potential issues emerge. These issues can be categorized broadly as technical issues, organizational issues, and issues related to commercial use of the spectrum.

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delegates the whole EMSO enterprise to the operations directorate.

[100] Department of Defense, DOD Directive 3610.01: Electromagnetic Spectrum Enterprise Policy, September 4, 2020, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/361001p.pdf?ver=2020-09-04-112353-317.

[101] Ibid., pp. 5-6.

[102] Department of Defense, Electromagnetic Spectrum Superiority Strategy, October 29, 2020, https://media.defense.gov/2020/Oct/29/2002525927/-1/-1/0/ ELECTROMAGNETIC_SPECTRUM_SUPERIORITY_STRATEGY.PDF.

[103] Ibid., p. i.

[104] Department of Defense, Electromagnetic Spectrum Strategy, September 11, 2013, https://archive.defense.gov/news/dodspectrumstrategy.pdf.

[105] Department of Defense, Electronic Warfare Strategy, 2017.

[106] P.L. 116-283 §152.

[107] This section was written by John R. Hoehn and Jill C. Gallagher.

Technical Challenges

This section discusses several potential technical issues associated with the spectrum. These include communications system interoperability, adversary technological development, and spectrum sharing technologies to enable commercial applications.

Communications System Interoperability

One challenge the DOD is confronted with is system interoperability both between individual weapons systems as well as between each of the military services. This issue has been documented with the F-22 and F-35 fighter aircraft developing incompatible data link protocols—the F-22 uses the intra-flight data link (IFDL) and the F-35 uses the multifunction advanced data link (MADL)—preventing these two Air Force fighter jets from sharing information with each other.[108] Each service develops its command, control, and communications systems to meet their individual needs. For instance, the Navy uses the AEGIS ballistic missile defense system—which is installed on guided missile cruisers and destroyers—which is currently unable to transmit radar data to the Army's Integrated Battle Command System (IBCS) which performs a similar function.

As mentioned, 5G encompasses low-band, mid-band, and high-band spectrum. DOD uses all three bands for its operations. While the bulk of its holdings are in the low-band and mid-band spectrum, DOD also uses high-band (including millimeter wave or MMW) frequencies for high-profile military applications such as Advanced Extremely High Frequency satellites that provide assured global communications for U.S. forces. Coordinating investments across four branches of government, three bands of spectrum, and across multiple geographies is a challenge.

The Defense Innovation Board and FCC Commissioner Rosenworcel have suggested that DOD should focus on sub-6 GHz deployments; they argue that the rest of the world, including China, is deploying 5G for military use in the low-band and mid-band first, and that the U.S. should do the same so as to (a) not fall behind other countries in sub-6 GHz deployments, and (b) ensure U.S. forces may be able to operate and interoperate with those countries when abroad.

Industry observers assert that the significant innovations will come in the MMW spectrum, including high-speed, low latency applications, providing the U.S. a competitive edge in the global defense market and on the battlefield. Still others assert that investments across all three bands will benefit DOD as 5G offers greater capacity, speeds, functionality, customization, and security. In deciding DOD appropriations, Congress may consider where and how federal funds for 5G should be invested.

Adversary Spectrum Interference Developments

Another potential issue for Congress is balancing spectrum needs of commercial users and consumers, and at the same time ensuring DOD has the spectrum it needs to keep pace with adversaries. The DOD states "[s]ince modern military operations are critically dependent on the EMS, a key goal of our adversaries and enemies is to deny our ability to use it successfully."[109] After observing how the U.S. military operates, potential adversaries like Russia and China have

[108] Brian W. Everstine, "The F-22 and the F-35 Are Struggling to Talk to Each Other … And to the Rest of USAF," *Air Force Magazine*, January 29, 2018, at https://www.airforcemag.com/article/the-f-22-and-the-f-35-are-struggling-to-talk-to-each-other-and-to-the-rest-of-usaf/.

[109] Department of Defense, *Joint Electromagnetic Spectrum Operations*, JP 3-85, Washington, DC, March 22, 2020, p. I-3, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_85.pdf?ver=2020-04-09-140128-347.

identified the U.S. military' reliance on the spectrum as a potential vulnerability. As a result, these potential adversaries have focused on challenging the U.S. military's network and EW capabilities—these systems are part of an overall approach called anti-access/area denial (A2/AD) which are intended to challenge the ability of the military from entering a contested area like the Baltic states or the South China Sea.[110] The FY2019 National Defense Authorization Act (NDAA) required DOD to contract an independent assessment of EW capabilities, with a report due October 1, 2019.[111] The Center for Strategic and Budgetary Assessments ultimately performed this assessment, providing an overview of adversary capabilities and doctrines.[112]

For more than a decade, the Russian military has focused on modernizing its forces, with a particular emphasis on command, control, communications, and computers (C4) and ISR systems, of which EW plays an important part. According to military analyst Robert McDermott, the Russian military views electronic warfare as a "type of armed struggle using electronic means against enemy C4ISR to 'change the quality of information,' or using electronic means against various assets to change the condition of the operational environment."[113] McDermott describes a close relationship between Russian signals intelligence forces and EW forces, where several EW units perform SIGINT functions. The Russian military's emphasis on EW may create problems for U.S. military forces if the Russians are able to deny significant portions of the EMS.

Most of the focus on Chinese EW operations has been on the air, maritime, and space domains. According to *Jane's Defence Weekly*, China has invested substantial resources into science and technology initiatives focused on improving its network and electronic warfare capabilities.[114] These investments include ground-based sensors and jammers, space-based intelligence assets, and a number of airborne jammers.[115] China is also investing in unmanned systems that could potentially swarm to provide desired effects, including SIGINT interceptions and electronic attack.[116] China has also focused on developing advanced jammers and anti-satellite technologies to deny U.S. forces access to satellites.[117] For example, in 2007, China demonstrated its ability to launch an anti-satellite weapon to destroy an old weather satellite in low earth orbit. According to the 2020 Annual Report on China Military Power, the DOD

[110] For more information on adversary electronic warfare capabilities see CRS Report R45919, *Ground Electronic Warfare: Background and Issues for Congress*, by John R. Hoehn.

[111] P.L. 115-232 §255.

[112] Bryan Clark, Whitney M. McNamara, and Timothy A. Walton, *Winning the Invisible War: Gaining an Enduring U.S. Advantage in the Electromagnetic Spectrum*, Center for Strategic and Budgetary Assessments, Washington, DC, November 20, 2019, https://csbaonline.org/research/publications/winning-the-invisible-war-gaining-an-enduring-u.s-advantage-in-the-electromagnetic-spectrum.

[113] Robert N. McDermott, Russia's Electronic Warfare Capabilities to 2025, p. 3, International Centre for Defence and Security, September 2017. See Department of Defense, Defense Intelligence Agency, Russia Military Power, Building a Military to Support Great Power Aspirations, 2017, p. 42.

[114] Tate Nurkin, Kelly Bedard, James Clad, et al., China's Advanced Weapons Systems, IHS Jane's, May 12, 2018, p. 11, https://www.uscc.gov/sites/default/files/Research/Jane%27s%20by%20IHS%20Markit_China%27s%20Advanced%20Weapons%20Systems.pdf.

[115] Elsa Kania, China's Strategic Situational Awareness Capabilities, Center for Strategic and International Studies, Washington, DC, July 29, 2019, https://ontheradar.csis.org/issue-briefs/china-situational-awareness/.

[116] Tate Nurkin, Kelly Bedard, James Clad, et al., China's Advanced Weapons Systems, IHS Jane's, May 12, 2018, p. 41, https://www.uscc.gov/sites/default/files/Research/Jane%27s%20by%20IHS%20Markit_China%27s%20Advanced%20Weapons%20Systems.pdf.

[117] Department of Defense, Defense Intelligence Agency, China Military Power: Modernizing a Force to Fight and Win, 2019, p. 42.

reported that "the PRC is developing electronic warfare capabilities such as satellite jammers; offensive cyber capabilities; and directed-energy weapons."[118]

A challenge for DOD has been in keeping pace with rapidly evolving technologies and coordinating information on adversaries' technologies and capabilities across DOD components.[119] In December 2018, the Government Accountability Office (GAO) issued a report stating that adversaries are developing electronic attack weapons to target U.S. systems with sensitive electronic components, such as military sensors, communication, navigation, and information systems.[120] The Senate Armed Services Committee, citing the report, stated, "These weapons are intended to degrade U.S. capabilities and could restrict situational awareness or may affect military operations. The committee is concerned about the extent to which [DOD] is planning and preparing to defend itself and operate in an environment where peer and near-peer adversaries could use existing and emerging capabilities that degrade use of the electromagnetic spectrum."[121]

Spectrum Sharing

In the past, repurposing efforts have focused on reallocating spectrum from federal to nonfederal use. As spectrum-sharing technologies emerged, Congress encouraged not only the reallocation of spectrum from federal to nonfederal entities, but also sharing between federal and commercial users. For example, the Middle Class Tax Relief and Job Creation Act of 2012 allowed federal agencies to receive payments for costs incurred when they are asked to relocate due to a spectrum auction or when they agree to share use of their spectrum.[122] The Spectrum Pipeline Act of 2015 appropriated funds for federal agencies to engage in planning and to conduct studies and analyses to examine the potential for spectrum reallocation or sharing.[123]

DOD has participated in several spectrum-sharing initiatives, some of which have resulted in the reallocation or shared use of spectrum.[124] For example, DOD, the Department of Homeland Security (DHS), the Federal Aviation Administration (FAA), and the National Oceanic and Atmospheric Administration (NOAA) have studied the potential to combine surveillance, air safety, and weather radar applications into a single, spectrum-conserving "system of systems" by 2024. This system would allow the agencies to vacate 30 MHz of spectrum in the 1300–1350 band, thus making it available for reallocation for shared federal and nonfederal use. Additionally, DOD plans to conduct a comprehensive engineering study to determine the potential for introducing advanced wireless services in this band without harming critical government

[118] Department of Defense, *Military and Security Developments Involving the People's Republic of China 2020*, Washington, DC, September 2020, p. 65, https://media.defense.gov/2020/Sep/01/2002488689/-1/-1/1/2020-DOD-CHINA-MILITARY-POWER-REPORT-FINAL.PDF.

[119] Sydney J. Freedberg, Jr., "Who'll Fix EW? Task Force Gropes for Answers," *Breaking Defense*, December 18, 2019, https://breakingdefense.com/2019/12/wholl-fix-ew-task-force-gropes-for-answers/.

[120] U.S. Government Accountability Office, *National Security: Long-Range Emerging Threats Facing the United States As Identified by Federal Agencies*, GAO-19-204SP, December 2018, p. 4, https://www.gao.gov/assets/700/695981.pdf.

[121] U.S. Congress, House Committee on Armed Services, *Report of the Committee on Armed Services on* H.R. 2500 *together with Additional and Dissenting Views*, H.Rept. 116-120, 116th Cong., 1st sess., June 19, 2019, 36-763 (Washington: GPO, 2019), p. 69, https://www.govinfo.gov/content/pkg/CRPT-116hrpt120/html/CRPT-116hrpt120.htm.

[122] P.L. 112-96, Title VI, Subtitle G—Federal Spectrum Relocation, Section 6701 (a)(1)(B).

[123] P.L. 114-74, Title X—Spectrum Pipeline, Section 1005 (a).

[124] Mark Rockwell, "DOD looks to share more spectrum," *Defense Systems*, March 1, 2018, https://defensesystems.com/articles/2018/03/01/ntia-dod-spectrum-5g.aspx.

operations.[125] Agencies began studying the reallocation and sharing potential of the spectrum in 2017, and are still actively studying potential use of the band. The studies are expected to inform future repurposing decisions.[126]

On August 10, 2020, the White House and DOD announced that a 100 MHz block of contiguous mid-band spectrum in the 3450-3550 MHz band will be made available for commercial use (e.g., 5G), and is expected to be auctioned in 2021. DOD leveraged technical work performed by the NTIA to "devise a spectrum sharing framework that supports industry's need for additional mid-band spectrum while protecting critical national security requirements."[127] At its September 30, 2020 meeting, the FCC adopted a Further Notice of Proposed Rulemaking (FNPRM) allocating the 3.45-3.55 GHz spectrum band for flexible-use service. It seeks comment on an appropriate regime to coordinate nonfederal and federal use and proposes a band plan, as well as technical, licensing, and competitive bidding rules for the band, signaling that the FCC is moving forward on the 2021 auction date.[128]

In addition, new technologies that would enable dynamic spectrum sharing—automated sharing between federal and nonfederal users—are under development.[129] For example, in September 2019, the FCC approved a spectrum sharing arrangement between commercial and federal users in the 3550-3700 MHz band (also known as Citizens Broadband Radio Service or CBRS), whereby commercial users (licensed and unlicensed) will share spectrum with incumbent DOD users. DOD will have priority access when needed while still allowing for licensed and unlicensed use.

In December 2019, DOD issued a special notice seeking input from industry on 5G technology development, including dynamic spectrum sharing technologies.[130] DOD and the Department of the Air Force sought input on effective methodologies (hardware, software, and systems) for sharing or coexistence between airborne radar systems and 5G cellular systems in shared (completely or partially overlapping) spectral bands. The intent is to evaluate the impact of the 5G network on airborne radar systems and the radar systems' impact on the 5G network, employing both active and passive techniques to enable sharing or coexistence. In September 2020, DOD issued a request for information seeking new methods to facilitate spectrum sharing between military and civilian users, and to identify issues of concern related to sharing spectrum for DOD.[131]

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[125] Office of Science and Technology Policy, *Emerging Technologies and Their Expected Impact on Non-Federal Spectrum Demand*, May 2019, https://www.whitehouse.gov/wp-content/uploads/2019/05/Emerging-Technologies-and-Impact-on-Non-Federal-Spectrum-Demand-Report-May-2019.pdf.

[126] U.S. Department of Commerce, *Annual Report on the Status of Spectrum Repurposing*, August 2019, https://www.ntia.doc.gov/files/ntia/publications/spectrum_repurposing_report_august_2019.pdf.

[127] U.S. Department of Defense, "White House and DOD Announce Additional Mid-Band Spectrum Available for 5G by the end of the Summer," press release, August 10, 2020, https://www.defense.gov/Newsroom/Releases/Release/Article/2307275/white-house-and-dod-announce-additional-mid-band-spectrum-available-for-5g-by-t/.

[128] FCC, "FCC Moves to Free Up 100 Megahertz of Critical Mid-Band Spectrum in the 3.45-3.55 GHz Band for 5G," press release, September 30, 2020, https://docs.fcc.gov/public/attachments/DOC-367236A1.pdf.

[129] The CBRS spectrum sharing arrangement is being used to model for other spectrum sharing arrangements. National Telecommunications and Information Agency, "Spectrum Sharing Model Gaining Ground," press release, May 1, 2019, https://www.ntia.doc.gov/blog/2019/spectrum-sharing-model-gaining-ground.

[130] U.S. Department of Defense, "DOD Issues Special Notice Seeking Input From Industry on 5G Technology Development," press release, December 2, 2019, https://www.defense.gov/Newsroom/Releases/Release/Article/2029707/dod-issues-special-notice-seeking-input-from-industry-on-5g-technology-developm/.

[131] DOD, Request for Information, *Defense Spectrum Sharing Request for Information*, Published September 18, 2020, https://beta.sam.gov/opp/4851a65e2b2d4d73865a0e9865b0c28a/view?keywords=spectrum&sort=-modifiedDate&

While policymakers and users are both interested in spectrum sharing, and see it as a way of extending spectrum access for new users, the policies, approaches, technologies, and applications are still emerging and may face challenges. Introducing new users into spectrum bands creates a potential for interference with military capabilities; detecting and mitigating interference is a challenge. Prioritization of use is another challenge, as is policy control and coordination with secondary users.[132] Further, to maximize use of shared spectrum, users may need to know when spectrum is being used and when it is available which may present challenges for DOD, as it may not want to share that information publicly.

On the one hand, industry stakeholders say that military and other federal users have more spectrum than they need and that holding large swathes of spectrum for future use inhibits innovations and restricts economic advancement.[133] On the other hand, some defense advocates say that as commercial use of spectrum is increasing, so is military use. These observers note that agencies holding large swathes of spectrum see only risks in relinquishing spectrum; they note, "no military planner would want to be known as the person who gave back spectrum subsequently needed."[134] The challenge for Congress is in encouraging policies that enable the most efficient use of spectrum, while still protecting and prioritizing DOD mission critical functions.

DOD Spectrum Organizational Issues[135]

Over the past several years, Congress has expressed interest in the DOD's organization of spectrum-related issues. The EW Executive Committee—led by the Deputy Secretary of Defense—is tasked with synchronizing and integrating EW across DOD components by sharing tactics, techniques, procedures, intelligence, and technologies. The EW EXCOM is responsible for establishing DOD EW policy by recommending resource allocation changes and proposing electronic warfare governance, management, organizational, and operational reforms.[136] The FY2019 NDAA mandated the creation of an EW Cross Functional Team to develop an electronic warfare strategy, including assessments of vulnerabilities and capability gaps,[137] leading to an acquisition plan.

The NDAA for FY2019 (P.L. 115-232, Section 1053) directed DOD to establish a cross-functional team to oversee the implementation of an integrated spectrum strategy. The intent is to meld two existing strategies, DOD's 2013 electromagnetic spectrum strategy developed by the chief information office (CIO) and the department's electronic warfare strategy, into a single

index=&is_active=true&page=1.

[132] Frank Rayal, "Challenges & Impediments to Implementing Spectrum Sharing," *Frank Rayal (blog)*, September 24, 2012, "https://frankrayal.com/2012/09/24/challenges-impediments-to-implementing-spectrum-sharing/.

[133] CTIA, "Benefits from Clearing Federal Spectrum Helps Government Agencies Modernize Operations, New CTIA Paper Finds," press release, August 11, 2020, https://www.ctia.org/news/release-benefits-from-clearing-federal-spectrum-helps-government-agencies-modernize-operations-new-ctia-paper-finds.

[134] Roslyn Layton, "GPS Interference Fears Are Today's Y2K, Says Former UK Spectrum Director," *Forbes*, May 8, 2020, https://www.forbes.com/sites/roslynlayton/2020/05/08/gps-interference-fears-are-todays-y2k-says-former-uk-spectrum-director/#79d799e17329.

[135] This section was written by John R. Hoehn.

[136] 10 U.S.C. §113 Notes.

[137] P.L. 115-232 §918.

policy:[138] the Electromagnetic Spectrum Superiority Strategy.[139] In April 2019, DOD stood up the Electromagnetic Spectrum Operations (EMSO) Cross Functional Team, comprised of senior members from each branch, the Joint Staff, U.S. Strategic Command, Cyber Command, and other offices. This organization has been active in updating DOD spectrum policy and strategy. In May 2020, the Joint Staff released new doctrine on Joint Electromagnetic Spectrum Operations, elevating the spectrum to a maneuver space.[140] On September 4, 2020, DOD issued DOD Directive 3610.01, Electromagnetic Spectrum Enterprise Policy, which sets DOD policy and roles and responsibilities for integrated DOD electromagnetic spectrum operations.[141] On October 29, 2020, the EMS Operations Cross Functional Team authored the DOD Spectrum Superiority Strategy, which was signed by the Secretary of Defense.[142] This strategy recognizes the importance of spectrum in support of military operations, and combines two traditional separate disciplines—electronic warfare and spectrum management—to take a holistic view of the DOD spectrum enterprise. Finally, the FY2021 NDAA transfers responsibility for electromagnetic spectrum operations from Strategic Command to an appropriate entity within DOD.[143]

Commercial Demand for Federal Spectrum

As the nation continues to experience significant growth in commercial wireless services (e.g., mobile phones, mobile applications, video streaming, Wi-Fi), demand for spectrum has increased. To meet current commercial and consumer demands, the U.S. government has identified spectrum that is optimal for wireless communication use. Sometimes the spectrum targeted for wireless services is in use by other commercial users (e.g., radio and television broadcasters, satellite communication providers). Sometimes the spectrum targeted is in use by federal agencies. Since DOD holds spectrum across multiple bands, it has been affected by effort to reallocate spectrum for commercial wireless use.

The growth in commercial wireless services has produced new revenues and new jobs for the United States.[144] Hence the challenge for Congress is in balancing the allocation of spectrum for commercial and consumer wireless services while protecting federal agency use of spectrum that support mission-critical functions. This balance was recently demonstrated with the FCC's Auction 107 for C-Band spectrum, which garnered approximately $81 billion from bidders.[145]

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[138] The EMSO CFT is in the process of developing a new EMS strategy and anticipates releasing the strategy by the end of 2020. Department of Defense, *Electromagnetic Spectrum Strategy*, September 11, 2013, https://dodcio.defense.gov/Portals/0/Documents/Spectrum/ESS.pdf.

[139] Lauren C. Williams, "DOD Preps New Electromagnetic Spectrum Strategy," *Defense Systems*, December 23, 2019, https://defensesystems.com/articles/2019/12/23/dod-spectrum-warfare-williams.aspx.

[140] While a maneuver space is not considered a domain, this implies

[141] Department of Defense, *DOD Directive 3610.01: Electromagnetic Spectrum Enterprise Policy*, September 4, 2020, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/361001p.pdf?ver=2020-09-04-112353-317.

[142] Department of Defense, *Electromagnetic Spectrum Superiority Strategy*, October 29, 2020, https://media.defense.gov/2020/Oct/29/2002525927/-1/-1/0/ ELECTROMAGNETIC_SPECTRUM_SUPERIORITY_STRATEGY.PDF.

[143] P.L. 116-283 §152 Transfer of Responsibilities and Functions Relating to Electromagnetic Spectrum Operations. This provision originated from S. 4049 §173, which would have transferred electromagnetic spectrum operations from Strategic Command to the Chairman of the Joint Chiefs of Staff as a Chairman's Controlled activity.ro

[144] Recon Analytics, LLC, "How America's 4G Leadership Propelled the U.S. Economy," April 16, 2018, https://api.ctia.org/wp-content/uploads/2018/04/Recon-Analytics_How-Americas-4G-Leadership-Propelled-US-Economy_2018.pdf.

[145] Federal Communications Commission, "Auction 107 - 3.7 GHz," press release, January 15, 2021, https://auctiondata.fcc.gov/public/projects/auction107.

Federal agencies hold various segments of spectrum that commercial entities may be able to use for wireless services. Since DOD is the largest holder of federal frequencies, policies to reallocate spectrum for commercial use often affect DOD. As Congress considers policies to allocate additional spectrum for commercial use, it may consider increasing demands for spectrum, the impact on DOD systems and uses, unintended frequency interference, the interagency process for allocating spectrum, and DOD's ability to anticipate future spectrum needs.

Increasing Demand for Spectrum

As more people are using more data on more devices and as new technologies emerge (5G), demand for mobile data (e.g., video) is increasing. Cisco, the U.S.-based network equipment maker, reported that in 2018, "global mobile data traffic amounted to 19.01 exabytes per month;[146] by 2022, mobile data traffic is expected to reach 77.5 exabytes per month worldwide,"[147] which will increase demand for additional spectrum.

To accommodate new technologies, more users, and more data-intensive applications (e.g., video streaming, gaming), global telecommunications providers and equipment makers around the world developed 5G wireless networks and technologies. 5G technologies promise increased speeds, improved connectivity, and reduced latency (i.e., lag time when sending commands from your device). However, for 5G, providers need large swathes of spectrum (100 MHz blocks) in the low-band (below 1 GHz), mid-band (1-6 GHz), and high-band (above 6 GHz) radio spectrum. Providers expect that the 5G solution—additional spectrum and new 5G technologies—will help to meet increasing demands for mobile data, support advanced 5G services to businesses, and yield new 5G applications, including new military applications.[148]

However, the spectrum is already crowded with users, including federal agency users. DOD is allocated about 40% of federally assigned spectrum,[149] including significant frequency bands in the 1-6GHz range—prime spectrum for mobile telecommunication technologies. Some stakeholders and policymakers have called for the reallocation of federal agency spectrum for commercial use, or incentives for some federal agencies to relinquish or share spectrum for 5G use.[150] DOD asserts that its spectrum supports military operations, and the research and development of advanced technologies, thus should remain with DOD.

Starting in 1993, the Omnibus Budget Reconciliation Act (OBRA),[151] required the Secretary of Commerce to identify at least 200 MHz of spectrum used by the federal government for reallocation to new spectrum-based technologies (i.e., commercial use). Year after year, the U.S. government has continued to reallocate spectrum from federal to commercial wireless use. In its first Annual Report on the Status of Spectrum Repurposing (2019), NTIA notes, "[t]o date, most repurposing activities and the statutory mandates for repurposing focus on accommodating non-federal uses and have not directed the repurposing of spectrum to new federal uses; they also

[146] An average person uses about 2-3 gigabytes per month. Collectively in 2018, consumers used about 19 billion gigabytes per month. In 2022, consumers are expected to use 77.5 billion gigabytes per month.

[147] https://www.statista.com/statistics/271405/global-mobile-data-traffic-forecast/

[148] CRS In Focus IF11251, *National Security Implications of Fifth Generation (5G) Mobile Technologies*, by John R. Hoehn and Kelley M. Sayler.

[149] U.S. Government Accountability Office, NTIA Planning and Processes Need Strengthening to Promote the Efficient Use of Spectrum by Federal Agencies, GAO-11-352, April 2011, p. 21, https://www.gao.gov/assets/320/318264.pdf.

[150] https://www.politico.com/news/agenda/2020/02/22/pentagon-airwaves-midband-106240.

[151] P.L. 103-66.

prioritize exclusive non-federal use over sharing."[152] Congress may require the reallocation of specific spectrum bands, call for the identification of certain amounts of spectrum (e.g., 255 MHz below 6 GHz), or call for testing and studies to identify appropriate spectrum for commercial use.[153] Since DOD holds about 40% of the federally held spectrum,[154] it can be affected by these policies.[155]

Congress has tried to assess and address the impact of federal spectrum policies on agencies. For example, in 2004 Congress established a program to help cover the costs that federal agencies incur when spectrum is reallocated. Congress enacted the Commercial Spectrum Enhancement Act (CSEA),[156] which created the Spectrum Relocation Fund (SRF). The SRF used revenues from spectrum auctions to provide funding to defray the costs of relocating federal users to new bands. However, as wireless technology use increased, and demand for mobile data continued to rise, the U.S. government continued to examine and reallocate spectrum to meet emerging demands. Some have argued that a piecemeal approach to spectrum planning is ineffective.[157] They say it does not provide companies or affected federal agencies with enough time or information to plan future investments. Advocates assert that a long-term spectrum plan or pipeline will allow industry to plan future investments and agencies to plan future improvements, reduce the time it takes to bring spectrum to market, and perhaps assist in resolving ongoing spectrum disputes.[158] In 2018, two spectrum planning initiatives were launched.

The FCC developed the 5G FAST Plan, which identified spectrum for 5G use, and streamlined regulations to speed 5G deployment.[159] This plan provides insight into FCC actions (e.g., future reallocations, auctions); however, the GAO found that the plan was not developed with outside entities, including the NTIA or other relevant stakeholders, including carriers.[160] In 2018, the President directed the NTIA to develop a National Spectrum Strategy to set forth a "balanced, forward-looking, flexible, and sustainable approach to spectrum management."[161] Federal agencies were directed to review current frequency assignments and spectrum usage to identify

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[152] Ibid.

[153] U.S. Department of Commerce, *Annual Report on the Status of Spectrum Repurposing*, August 2019, https://www.ntia.doc.gov/files/ntia/publications/spectrum_repurposing_report_august_2019.pdf.

[154] U.S. Government Accountability Office, *NTIA Planning and Processes Need Strengthening to Promote the Efficient Use of Spectrum by Federal Agencies*, GAO-11-352, April 2011, p. 21, https://www.gao.gov/assets/320/318264.pdf.

[155] George Leopold, "DOD returns fire on spectrum relocation," *EE|Times*, August 30, 2001, https://www.eetimes.com/dod-returns-fire-on-spectrum-relocation/#.

[156] Title II of P.L. 108-494.

[157] U.S. House of Representatives, Committee on Energy and Commerce, Subcommittee on Communications and Technology, hearings, "Our Wireless Future: Building A Comprehensive Approach to Spectrum Policy," 116th Cong., 1st sess., July 16, 2019, https://energycommerce.house.gov/committee-activity/hearings/hearing-on-our-wireless-future-building-a-comprehensive-approach-to. See testimony of Derek Khlopin, Senior Policy Advisor, NTIA, at https://energycommerce.house.gov/sites/democrats.energycommerce.house.gov/files/documents/1_Testimony_Khlopin.pdf. See also testimony of Scott Bergmann Senior Vice President, Regulatory Affairs CTIA, at https://energycommerce.house.gov/sites/democrats.energycommerce.house.gov/files/documents/2_Testimony_Bergmann.pdf.

[158] *White House 5G Summit* (recorded event), September 28, 2018, https://www.youtube.com/watch?v=lBbY8fvTidU.

[159] FCC, "5G FAST Plan," https://www.fcc.gov/5G.

[160] U.S. Government Accountability Office, *5G Deployment: FCC Needs Comprehensive Strategic Planning to Guide its Efforts*, GAO-20-468, June 2020, pp. 12-13, https://www.gao.gov/assets/710/707530.pdf.

[161] White House, Office of the Press Secretary, "Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future," presidential memorandum, October 25, 2018, https://www.whitehouse.gov/presidential-actions/presidential-memorandum-developing-sustainable-spectrum-strategy-americas-future/.

spectrum that could be reallocated or shared with commercial uses. NTIA held a Spectrum Policy Symposium in August 2019 to seek public comment on the plan. DOD speakers noted that, with new technologies and cooperation with commercial users, DOD is exploring opportunities to share spectrum.[162] NTIA has reported that the National Spectrum Strategy is under development.

Congress may be interested in encouraging coordination between the agencies to balance the needs of commercial 5G providers and users and the mission critical needs of DOD. On the one hand, reallocating spectrum from DOD may help to speed deployment of 5G networks, spur the development of 5G use cases, and strengthen the U.S. position in the global 5G market. On the other hand, DOD provides critical national defense functions; taking spectrum from DOD could affect military operations and result in the permanent loss of spectrum for DOD uses, including critical defense operations and future capabilities.

Unintended Commercial Frequency Interference[163]

As new users, technologies, and services are introduced to the spectrum, the potential for interference may increase.[164] Interference occurs when unwanted radio frequency signals disrupt the transmission of information in systems operating in the same band or in nearby bands. Interference is a persistent issue in spectrum management, and introducing new technologies, new users, and broadening spectrum access (e.g., through spectrum sharing or allowing flexible use of spectrum) may increase the potential for harmful interference.[165]

As the U.S. government seeks to use spectrum more flexible to support new uses, or more cooperatively, through a shared approach, interference claims are likely to increase. For DOD, Congress has enacted legislation to protect DOD systems from interference. For example, pursuant to 10 U.S.C. §2281, Congress had authorized DOD to object "to any restriction on the GPS System proposed by the head of a department or agency of the United States outside DOD that would adversely affect the military *potential* of GPS" [emphasis added]. Additionally, in Section 1698 of the National Defense Authorization Act for Fiscal Year 2017 (P.L. 114-328)—codified at Section 343 of the Communications Act—prohibits the FCC from approving commercial terrestrial operations in the bands proposed by Ligado "until 90 days after the Commission resolves concerns of widespread harmful interference by such operations to covered GPS devices."[166] While DOD did express its concerns to the FCC on the Ligado project, the FCC asserted that the conditions it placed on Ligado (e.g., reducing power levels, creating a guard band, reporting base station locations) would mitigate interference concerns.

A recent dispute with Ligado Networks, LLC has highlighted key interference issues. On April 20, 2020, the FCC unanimously approved an application by Ligado Networks LLC (Ligado) to "deploy a low-power [9.8 decibel watts (dBW)] terrestrial nationwide network in the 1526-1536

[162] NTIA, *NTIA Spectrum Policy Symposium Transcript*, September 10, 2019, p. 12, https://www.ntia.doc.gov/files/ntia/publications/09.10.19_npc_ntia_spectrum_policy_symposium.pdf.

[163] Fore a detailed discussion of potential 5G interference with the Global Positioning System, see the **Appendix**.

[164] Commerce Spectrum Management Advisory Committee (CSMAC), *Interference and Dynamic Spectrum Access*, Interim Report, May 19, 2010, p. 13, https://www.ntia.doc.gov/files/ntia/meetings/csmac_may19_idsa_final.pdf.

[165] John Pahl, "Market Mechanisms for Spectrum Management: Spectrum Liberalisation and Interference Management," Background Paper submitted to ITU Workshop, "Shaping Tomorrow's Network" Program, September 2006, https://www.scribd.com/document/60765650/Spectrum-Liberalisation-and-Interference-Management.

[166] This provision is related to an earlier proposal from Ligado submitted to the FCC, which federal agencies, including DOD, opposed. Details on the proposal, the federal agency opposition, and congressional intent is available in S.Rept. 116-236, pp. 75, 275.

MHz, 1627.5-1637.5 MHz, and 1646.5-1656.5 MHz bands [of the electromagnetic spectrum][167] that will primarily support Internet of Things (IoT) services."[168]

These frequency bands are traditionally used for satellite communications and position, navigation, and timing services, such as GPS.[169] DOD opposed this decision—along with the Department of Homeland Security, Department of Transportation (DOT), Department of the Interior, Department of Justice, the Federal Aviation Administration (FAA), and others.[170] That opposition was related to concerns that Ligado's proposed terrestrial network could interfere with signals from satellites to terrestrial GPS receivers and enabled devices.[171] Despite federal agency opposition, the FCC unanimously approved the project, with the conditions (e.g., reducing power, creating a guard band, reporting base station locations) that, the FCC commissioners assert, would avoid interference between the two systems.

An issue of consideration for Congress may be in setting acceptable interference thresholds, levels of acceptable risks that are consistent with international interference standards that will enable new technologies and protect DOD critical operations. Another area for Congress may be in the resolution process, how and when federal agency concerns about interference are heard, and how decisions may affect federal systems and operations. Congress may also consider broader issues related to wireless technologies (e.g., 5G, 6G), such as the allocation of spectrum among competing users and the impact of spectrum decisions on national security.

Interagency Disputes

Congress may review the process by which the FCC and the NTIA, or other federal agencies, resolve spectrum disputes. As noted, the FCC and NTIA operate under an MOU that requires spectrum planning and coordination. The NTIA represents federal agency concerns in meetings with the FCC. Some observers have questioned NTIA's ability to represent federal agency interests,[172] while others have questioned whether federal agencies should have to work through NTIA to express its concerns on FCC decisions.[173]

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[167] CRS In Focus IF11155, *Defense Primer: Military Use of the Electromagnetic Spectrum*, by John R. Hoehn.

[168] The FCC authorized Ligado to operate an Internet of Things network in the referenced frequency bands with conditions. Federal Communications Communication Order 20-48, at https://docs.fcc.gov/public/attachments/FCC-20-48A1.pdf.

[169] Testimony of Michael Griffin, Undersecretary of Defense for Research and Engineering, Dana Deasy, DOD Chief Information Officer, Gen John Raymond, Chief of Space Operations, and Thad Allen, Chairman of Space-Based Positioning Navigation and Timing National Advisory Board, before the U.S. Congress, Senate Armed Services Committee, *Department of Defense Spectrum Policy and the Impact of the Federal Communications Commission*, 116th Cong., 2nd sess., May 6, 2020.

[170] Letter from Douglas Kinkoph, Associate Administrator Performing the Delegated Duties of the Assistant Secretary of Communications and Information, to Hon Ajit Pai, Chairman of the Federal Communications Commission, April 10, 2020, at https://www.ntia.doc.gov/files/ntia/publications/ntia_letter_to_fcc_chairman_re_ligado_applications_4.10.20.pdf.

[171] CRS In Focus IF11558, *Spectrum Interference Issues: Ligado, the L-Band, and GPS*, by Jill C. Gallagher, Alyssa K. King, and Clare Y. Cho.

[172] U.S. Government Accountability Office, Interdepartment Radio Advisory Committee: IRAC Representatives Effectively Coordinate Federal Spectrum but Lack Seniority to Advise on Contentious Policy Issues, GAO-04-1028, September 2004, pp. 3-4, https://www.gao.gov/new.items/d041028.pdf.

[173] Testimony of Thad Allen, Chairman of Space-Based Positioning Navigation and Timing National Advisory Board, before the U.S. Congress, Senate Armed Services Committee, *Department of Defense Spectrum Policy and the Impact of the Federal Communications Commission*, 116th Cong., 2nd sess., May 6, 2020, p. 42, https://www.armed-services.senate.gov/imo/media/doc/20-21_05-06-2020.pdf.

As the federal government strives to make spectrum available for 5G services, several spectrum bands used for federal agency missions (DOD and other agencies) have been targeted for reallocation or repurposing, affecting federal agency investments and missions. This includes DOD concerns over the L-Band, DOT concerns over the reconfiguring of the 5.9 GHz band set aside for auto safety technologies, Department of Education concerns regarding the reallocation of the 2.5 GHz band from educational users, and the National Oceanic and Atmospheric Administration and the 24 GHz band used for weather forecasting.

Congress has proposed initiatives to improve spectrum management and reduce spectrum disputes. For example, the Senate-passed version of the FY2021 NDAA (S. 4049, enrolled, Section 1084) (c)), would direct the NTIA to evaluate a range of information technology (IT) modernization initiatives that would improve analysis of federal government spectrum use and management. Some in Congress have proposed updates to the MOU between the FCC and NTIA to clarify the government's spectrum management and reallocation process.[174] Others have suggested to Congress that a third-party, such as the White House Office of Science and Technology Policy (OSTP) or the National Academies of Science and Engineering, serve as a technical reviewer or as an arbiter of conflicting technical reports and interference disputes.[175]

As spectrum is reallocated or reconfigured, some federal agencies are protesting.[176] FCC has acknowledged that as demand for spectrum increases, and more users gain access to the spectrum, disputes are likely to increase as well. Congress may examine the interagency spectrum planning and dispute resolution processes to ensure that federal agency needs are heard, and that federal agency investments are protected and that federal agency missions continue to be supported.

Anticipating Future Spectrum Needs

In a report to the President by the Director of the Office of Science and Technology Policy (OSTP), the Director cites the primary use cases for 5G: (1) enhanced mobile broadband; (2) ultra-reliable and low latency communications; (3) massive machine type communications, also known as massive Internet of Things (IoT); (4) fixed wireless technologies; and (5) enhanced vehicle-to-everything (V2X). The Director notes that the identified use cases are driving research and development (R&D) activities, as well as the standardization activities taking place in the international standards development groups such as the International Telecommunications Union (ITU) and the Third Generation Partnership Project (3GPP). Some technology firms advocate for increased investments in R&D to give the United States a competitive edge in the commercial 5G market. DOD is supporting this R&D through the development of new technologies, such as the dynamic spectrum sharing technologies to support the more efficient use of spectrum by

[174] See discussion on MOU and arbiter for spectrum disputes during Senate hearing (video): U.S. Congress, Senate Committee on Commerce, Science, and Transportation, *The State of U.S. Spectrum Policy*, 116th Cong., 2nd sess., July 23, 2020.

[175] Ibid.

[176] Letter from Elaine L. Chao, Secretary, U.S. Department of Transportation, to Federal Communications Chairman Ajit Pai, November 20, 2019, https://www.highways.org/wp-content/uploads/2019/12/sec-chao-letter-5.9-11-20-19.pdf; Letter from Jim Blew, Assistant Secretary for Planning, U.S. Department of Education, to FCC Chairman Ajit Pai, June 7, 2019, https://ecfsapi.fcc.gov/file/10607076793462/190607-Education-EBSExParte.pdf; Letter from Douglas W. Kinkoph, Associate Administrator, NTIA, to FCC Chairman Pai, April 10, 2020, https://www.ntia.doc.gov/files/ntia/publications/ntia_letter_to_fcc_chairman_re_ligado_applications_4.10.20.pdf (this cover letter from NTIA was sent to the FCC, and includes letters from DOD to the Secretary of Commerce regarding concerns with recent spectrum decisions, DOD to NTIA on spectrum concerns, and a Memorandum from the Air Force to NTIA on spectrum concerns, signed by 12 members of this interagency spectrum working group).

deploying 5G in selected bases to measure and monitor performance, and experiment with the technologies.

The allocation of spectrum takes time, as does the buildout of a network that will operate in the band. Often, by the time the spectrum is allocated and networks built, new technologies are emerging. For example, future sixth generation (6G) communications technologies, along with emerging military communications technologies. These technologies will most likely use the spectrum differently than current systems; exactly how these systems will use the spectrum remains unclear.[177]

Potential Questions for Congress[178]

As Congress considers its role in spectrum policy and how the DOD manages its use of the spectrum, several potential issues and questions arise. Below are a few potential Congress may seek additional information:

- What actions can Congress or DOD take to ensure that mission critical systems that operate in various segments of the electromagnetic spectrum (both domestically and abroad) are interoperable?
- What changes, if any, should the DOD make in programs or investments in order to maintain a technological edge in the use of the electromagnetic spectrum over U.S. competitors?
- Does the U.S. government's plan for spectrum allocation sufficiently balance DOD requirements with the requirements of commercial applications? If so, how?
- What measures, if any, could accelerate spectrum repurposing, relocation, and/or sharing?
- Is DOD using the spectrum it has efficiently? How can DOD improve its spectrum efficiency? Is DOD adequately leveraging the spectrum to enable future concepts like Multi-Domain Operations, Distributed Maritime Operations, and JADC2? If so, how?
- As DOD relinquishes certain spectrum segments to commercial or shared use, how is it planning to ensure continued command and challenges in implementing 5G communications?

[177] Some analysts have suggested that 6G, for instance might use spectrum in the 200-1000 GHz range, however there are no official stands that have been identified. Future DOD use of the spectrum remains unclear other than the highlighted emerging technologies discussed earlier.

[178] This section was written by John R. Hoehn, Jill C. Gallagher, and Kelley M. Sayler.

Appendix. Ligado Networks[179]

Concerns Regarding the FCC-Approved Ligado Network for Mid-Band 5G Network

On April 20, 2020, the Federal Communications Commission (FCC) unanimously approved an application by Ligado Networks LLC (Ligado) to "deploy a low-power [9.8 decibel watts (dBW)] terrestrial nationwide network in the 1526-1536 MHz, 1627.5-1637.5 MHz, and 1646.5-1656.5 MHz bands [of the electromagnetic spectrum][180] that will primarily support Internet of Things (IoT) services."[181] These frequency bands are traditionally used for satellite operations.[182] The Department of Defense (DOD) opposed this decision, along with the Department of Homeland Security, Department of Transportation (DOT), Department of the Interior, Department of Justice, the Federal Aviation Administration (FAA), and others.[183] That opposition related to concerns that Ligado's proposed network could interfere with signals from satellites to Global Positioning System (GPS) receivers.[184] Congress may consider federal agency concerns, including DOD concerns related to mission-critical systems and the FCC's response, as it conducts oversight of the FCC's ruling. Congress may also consider broader issues related to fifth generation (5G) mobile technologies, such as the allocation of spectrum among competing users and the impact of spectrum decisions on national security.

DOD Concerns and Related Studies on GPS Interference

In both its formal response to the FCC's ruling and in its May 6, 2020, testimony before the Senate Armed Services Committee (SASC), DOD cited two primary studies that shaped its belief that the Ligado network "would cause unacceptable operational impacts and adversely affect the military potential of GPS": a 2018 DOT study and a 2016 classified study conducted by the U.S. Air Force (USAF).[185] The 2018 DOT study assessed the extent to which cellular base stations

[179] This section was written by John R. Hoehn and Kelley M. Sayler. For more information see, CRS Insight IN11400, *DOD Concerns About the FCC-Approved Ligado Network*, by Kelley M. Sayler and John R. Hoehn and CRS Insight IN11414, *The FCC-Approved Ligado Network and Potential Technical Issues for DOD Use of GPS*, by John R. Hoehn, Stephen M. McCall, and Kelley M. Sayler.

[180] CRS In Focus IF11155, *Defense Primer: Military Use of the Electromagnetic Spectrum*, by John R. Hoehn.

[181] The FCC authorized Ligado to operate an Internet of Things network in the referenced frequency bands with conditions. Federal Communications Communication Order 20-48, at https://docs.fcc.gov/public/attachments/FCC-20-48A1.pdf.

[182] Testimony of Michael Griffin, Undersecretary of Defense for Research and Engineering, Dana Deasy, DOD Chief Information Officer, Gen. John Raymond, Chief of Space Operations, and Thad Allen, Chairman of Space-Based Positioning, Navigation and Timing National Advisory Board, before the U.S. Congress, Senate Armed Services Committee, *Department of Defense Spectrum Policy and the Impact of the Federal Communications Commission*, 116th Cong., 2nd sess., May 6, 2020.

[183] Letter from Douglas Kinkoph, Associate Administrator Performing the Delegated Duties of the Assistant Secretary of Communications and Information, to Hon. Ajit Pai, Chairman of the Federal Communications Commission, April 10, 2020, at https://www.ntia.doc.gov/files/ntia/publications/ntia_letter_to_fcc_chairman_re_ligado_applications_4.10.20.pdf.

[184] CRS In Focus IF11558, *Spectrum Interference Issues: Ligado, the L-Band, and GPS*, by Jill C. Gallagher, Alyssa K. King, and Clare Y. Cho.

[185] See Department of Transportation, *Global Positioning System (GPS) Adjacent Band Compatibility Assessment*, April 2018, https://www.transportation.gov/sites/dot.gov/files/docs/subdoc/186/dot-gps-adjacent-band-final-reportapril2018.pdf, and written testimony of Dana Deasy, DOD Chief Information Officer, before the U.S. Congress, Senate Armed Services Committee, *Department of Defense Spectrum Policy and the Impact of the Federal*

with power levels ranging from -6 dBW to 31 dBW and cellular handsets of -7 dBW would interfere with GPS. (At the time of the study, Ligado proposed a base station power level of 32 dBW.) The study concluded that base stations at the proposed Ligado frequency would have to be limited to 9.8 dBW to ensure the protection of certified avionics in most scenarios. In conversation with CRS, DOT officials asserted that the protection of other categories of GPS equipment—including noncertified aviation, general location/navigation, high precision, timing, and space-based—could not be assured at this power level. DOD additionally recommended "that proposals for use of bands adjacent to GPS should not be approved unless they meet the transmission power levels described in the [DOT test]."[186] Based on these recommendations, Ligado submitted an amended application to the FCC, reducing its proposed power levels to 9.8 dBW.[187] Per the FCC ruling, Ligado also agreed to maintain a 23-MHz guard-band of unused spectrum designed to separate its transmissions from GPS, thus attempting to mitigate potential interference.

Details available in the public domain describing the technical parameters of the 2016 classified USAF study are limited; however, the USAF's formal response to the FCC ruling notes that its study,[188] which specifically tested potential interference with military GPS receivers, "supported the conclusions drawn from the DOT testing ... conducted during the same month." This may suggest that the study may not provide evidence that a Ligado network—using the FCC-approved specifications from the company's 2018 amended application—would necessarily interfere with GPS. Furthermore, according to FCC Chairman Ajit Pai,[189] DOD neither submitted nor attempted to submit the classified USAF study to the FCC for consideration. Nonetheless, DOD has continued to cite these studies in its public objections to the ruling.

Michael Griffin, former Under Secretary of Defense for Research and Engineering (USD R&E), has additionally asserted that any ground transmissions—regardless of power level—"would drown out the very weak signals that come from [GPS] satellites," likening the effect of the proposed Ligado network on GPS to attempting to listen to the rustling of leaves while 100 jet aircraft simultaneously took off.[190]

Statutory Obligations with Regard to Potential GPS Interference

DOD has noted its statutory obligation, pursuant to 10 U.S.C. §2281, to object "to any restriction on the GPS System proposed by the head of a department or agency of the United States outside DOD that would adversely affect the military *potential* of GPS" [emphasis added]. Although the

Communications Commission, 116th Cong., 2nd sess., May 6, 2020, at https://www.armed-services.senate.gov/imo/media/doc/Deasy_05-06-20.pdf.

[186] Letter from Douglas Kinkoph, Associate Administrator Performing the Delegated Duties of the Assistant Secretary of Communications and Information, to Hon. Ajit Pai, Chairman of the Federal Communications Commission, April 10, 2020.

[187] Letter from Gerard Waldron, Counsel to Ligado Networks LLC, to Marlene H. Dortch, Secretary to the Federal Communications Commission, May 31, 2018, at https://ecfsapi.fcc.gov/file/1053120688074/Ligado%20License%20Modification%20Cover%20Letter%20and%20Amendment%20(5-31-2018).pdf.

[188] Letter from Douglas Kinkoph, Associate Administrator Performing the Delegated Duties of the Assistant Secretary of Communications and Information, to Hon. Ajit Pai, Chairman of the Federal Communications Commission, April 10, 2020.

[189] Letter from Hon. Ajit Pai, Chairman of the Federal Communications Commission, to Rep. Donald Bacon et al., May 26, 2020, at https://docs.fcc.gov/public/attachments/DOC-364591A2.pdf.

[190] Spoken testimony of Michael Griffin, Undersecretary of Defense for Research and Engineering, before the U.S. Congress, Senate Armed Services Committee, *Department of Defense Spectrum Policy and the Impact of the Federal Communications Commission*, 116th Cong., 2nd sess., May 6, 2020.

DOT and the USAF studies do not appear to provide evidence that a Ligado network *would* adversely affect military GPS, neither definitively ruled out the *potential* for adverse effects. As a result, Secretary of Defense Mark Esper concluded, "Consistent with my statutory responsibilities, I believe there are too many unknowns and the risks are far too great to federal operations to allow Ligado's proposed system to proceed."[191]

DOD has additionally noted that Section 1698 of the National Defense Authorization Act for Fiscal Year 2017 (P.L. 114-328)—codified at Section 343 of the Communications Act—prevents the FCC from approving commercial terrestrial operations in the bands proposed by Ligado "until 90 days after the Commission resolves concerns of widespread harmful interference by such operations to covered GPS devices." DOD asserts that the FCC did not resolve such concerns prior to approving Ligado's application; paragraph 130 of the FCC ruling provides the FCC's justification for its belief that the concerns were "effectively resolved."[192]

FCC Response to Concerns About Potential GPS Interference

Several Commissioners have provided statements and written correspondence directly addressing how the FCC came to its decision. Commissioner Brendan Carr noted in a statement accompanying the FCC's decision that "after a thorough and multi-year review, the FCC's professional staff of engineers and other experts determined that we can advance America's 5G leadership while protecting GPS and other adjacent band services."[193] Commissioners Jessica Rosenworcel and Geoffrey Starks termed the decision "an extremely close call," but similarly noted in their joint statement of concurrence that, despite the concerns of DOD and others about potential GPS interference, "in the end, we are compelled to support the expert technical analysis done by the [FCC's] engineering staff."[194] In a series of letters, Chairman Ajai Pai has outlined the FCC's decisionmaking process, the data the commission used to make its determination, and the FCC's technical analysis of potential interference.[195]

[191] Letter from Hon. Mark Esper, Secretary of Defense, to Hon. Ajit Pai, Chairman of the Federal Communications Commission, November 18, 2019, at https://www.ntia.doc.gov/files/ntia/publications/ntia_letter_to_fcc_chairman_re_ligado_mss_atc_applications_dec._6_2019.pdf#page=6.

[192] Federal Communications Communication Order 20-48, at https://docs.fcc.gov/public/attachments/FCC-20-48A1.pdf.

[193] Statement of Commissioner Brendan Carr, Re: LightSquared Technical Working Group Report, IB Docket No. 11-109; LightSquared License Modification Application, IBFS Files Nos. SAT-MOD-20120928-00160-00161, SES-MOD-20121001-00872, IB Docket No. 12-340; New LightSquared License Modification Applications, IBFS File Nos. SES-MOD-20151231-00981, SAT-MOD20151231-00090, SAT-MOD-20151231-00091, IB Docket Nos. 11-109, 12-340; Ligado Amendment to License Modification Applications, IBFS File Nos. SES-MOD-20151231-00981, SAT-MOD-20151231-00090, SAT-MOD-20151231-00091, IB Docket No. 11-109, at https://docs.fcc.gov/public/attachments/FCC-20-48A2.pdf.

[194] Joint Statement of Commissioners Jessica Rosenworcel and Geoffrey Starks Concurring Re: LightSquared Technical Working Group Report, IB Docket No. 11-109; LightSquared License Modification Application, IBFS Files Nos. SAT-MOD-20120928-00160-00161, SES-MOD-20121001-00872, IB Docket No. 12-340; New LightSquared License Modification Applications, IBFS File Nos. SES-MOD-20151231-00981, SAT-MOD20151231-00090, SAT-MOD-20151231-00091, IB Docket Nos. 11-109, 12-340; Ligado Amendment to License Modification Applications, IBFS File Nos. SES-MOD-20151231-00981, SAT-MOD-20151231-00090, SAT-MOD-20151231-00091, IB Docket No. 11-109, at https://docs.fcc.gov/public/attachments/FCC-20-48A3.pdf.

[195] For list of congressional correspondence, see https://www.fcc.gov/chairman-pais-letters-congress.

Legislative Activity

The FY2021 National Defense Authorization Act (P.L. 116-283) contains five Ligado- or GPS interference-related provisions:

1. Section 1611 requires DOD to develop a plan for a resilient and survivable positioning, navigation, and timing capability within two years.[196] This provision would allow DOD to reprogram resources as needed to develop the plan.
2. Section 1661 prohibits funds for retrofitting GPS devices or networks that use GPS for the purposes of "[mitigating] harmful interference from commercial terrestrial operations using the 1526–1536 megahertz band, the 1627.5–1637.5 megahertz band, or the 1646.5–1656.5 megahertz band" (i.e., the bands approved for the Ligado network).[197]
3. Section 1662 prohibits funding for contracts with entities "that [engage] in commercial terrestrial operations using the 1525–1559 megahertz band or the 1626.5–1660.5 megahertz band unless the Secretary has certified to the congressional defense committees that such operations do not cause harmful interference to a Global Positioning System device of the Department of Defense."[198]
4. Section 1663 directs the Secretary of Defense to seek an independent technical assessment of the FCC's Ligado authorization order (FCC 20-48) from the National Academy of Sciences.[199] This assessment is to "evaluate the potential harmful interference concerns relating to Global Positioning System devices," review potential mitigation measures, and provide associated recommendations to the department.
5. Section 1664 prohibits the Secretary of Defense from obligating or expending funds to comply with the FCC's Ligado authorization order until the Secretary submits to the congressional defense committees an estimate of the cost associated with any potential interference-mitigation measures.[200]

[196] P.L. 116-283 §1611 Resilient and Survivable Positioning, Navigation, and Timing Capabilities.

[197] P.L. 116-283 §1661 Prohibition on Availability of Funds for Certain Purposes Relating to the Global Positioning System.

[198] P.L. 116-283 §1662 Limitation on Awarding Contracts to Entities Operating Commercial Terrestrial Communication Networks that Cause Harmful Interference with the Global Positioning System.

[199] P.L. 116-283 §1663 Independent Technical Review of Federal Communications Commission Order 20-48.

[200] P.L. 116-283 §1664 Estimate of Damages from Federal Communications Commission Order 20-48.

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