REPORT IN BRIEF

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A Strategy for Active Remote Sensing Amid Increased Demand for Radio Spectrum

A radar image strip over an optical image of the same region in the Sahara Desert. The radio waves penetrate the shallow sand to reveal an ancient drainage network. Source: NASA/JPL

Advances in affordable electronics and mobile wireless in recent years have significantly increased the demand for access to the radio spectrum and have led to discussions in both government and industry about new approaches for reducing radio frequency interference between users and services. Researchers using active remote sensing at radio frequencies to study and predict changes in Earth's environment and the local solar system have an important stake in the policies that affect spectrum allocation and use. *A Strategy for Active Remote Sensing Amid Increased Demand for Radio Spectrum*, a study carried out for NASA by the National Academies of Sciences, Engineering, and Medicine, documents the importance of active remote sensing in serving societal needs and identifies current and future threats to the effective use of the frequencies required for active remote sensing.

The forward-looking approach laid out in this report will allow scientists to continue to provide the nation and world with a better understanding of Earth and the local space environment while working cooperatively alongside other spectrum users. The Academies encourage federal agencies to better quantify the radio interference environment, facilitate spectrum sharing, and support additional spectrum allocations for specific scientific applications. The report also recommends the scientific community engage with policymakers on issues of spectrum management and work to identify opportunities to share bandwidth.

BACKGROUND

To support the presidential initiative for Spectrum Management for the 21st Century, the Academies conducted a survey of the scientific uses of the spectrum by passive (receive-only) means in 2010, resulting in *Spectrum Management for Science in the 21st Century*. The report, which had a significant impact in the Administration and Congress, identified sources of potentially dire interference to NASA's in-orbit and planned passive remote sensing observatories and to NSF's ground-based radio astronomy observatories. At the request of NASA, the Academies convened a committee of experts to undertake a similar study to explore the current and planned scientific use of the spectrum by active means with a focus on understanding current and potential vulnerabilities.

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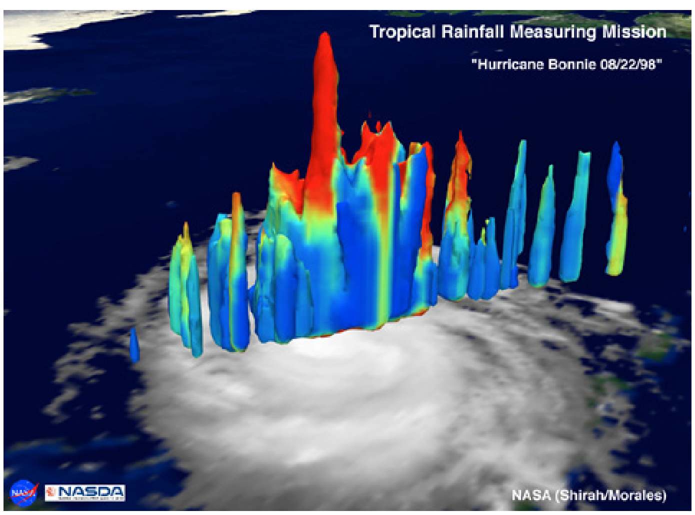
Active remote sensing involves using a transmitter and at least one receiver to measure the transmission or scattering properties of a medium at radio frequencies. Depending on the type of measurement, the transmitters and receivers can be mounted on ground-based, airborne, or satellite platforms. However, the proliferation of wireless technology has introduced an increasing amount of interference to active remote sensing systems, leaving regulators with the difficult task of balancing competing priorities in order to try and make the desired spectrum available to all users.

THE IMPORTANCE OF ACTIVE REMOTE SENSING

Active remote sensing delivers countless benefits to society and is an important tool for studying Earth and its environs. Spaceborne, airborne, and surface-operated active remote sensing instruments provide data that is critical for a wide range of applications including urban planning, agriculture, forestry, water management, sea ice mapping, post-disaster assessment, and spatial intelligence. Active remote sensing of the atmosphere saves lives and protects property by predicting severe weather events such as hurricanes and tornadoes. Active microwave sensors provide unique measurements that assist in global weather prediction, ship routing, commercial fishing, and wave forecasting. Active remote sensing is essential for understanding Earth's local space environment and for predicting the impacts of space weather events on our electricity-dependent society, while planetary radar astronomy makes it possible to track nearby asteroids and plan missions to extraterrestrial objects.



Example of 3D Precipitation Radar imagery for a hurricane. Source: NASA

CURRENT AND FUTURE THREATS

Radio Frequency Interference (RFI)

The frequencies used by active remote sensing have been carefully chosen to reveal the underlying science, and in most cases considerable expense has been incurred to operate in the chosen frequency range. For each type of measurement, it may be very difficult to relocate operations into other frequency bands. Thus, given that ongoing active remote sensing measurements are essential to protect society, there must be effective access to the required spectrum.

Radio frequency interference (RFI) refers to the unintended reception of a signal transmitted by an auxiliary source. Unlike passive science systems where regulatory effort is made to keep the allocated band free of other emitters, active science systems are often expected to share the band with other services, so signals from other radio services are often present to varying degrees. Potential sources of RFI to active sensing systems include commercial and amateur radio signals, ground-based radar, broadband communication systems, and GPS. While there is evidence to indicate that RFI occurs fairly frequently at C-band and lower frequencies, its occurrence is rare at higher frequencies. Preliminary evidence suggests that active sensing instruments do not normally cause RFI to other users, but other users have negatively impacted the performance of active sensing instruments.

FINDING: The RFI environment has been observed to be growing worse in some bands. Within the heavily used and well-studied L-band allocation of 1215-1300 MHz, the amount of RFI observed worldwide has steadily increased over time. The ESA has reported an increase in RFI at the C-band.

FINDING: Established, high-value science radar measurements at the C-band face near-term threats due to the planned expansion of commercial services in the Earth Exploration-Satellite Service-Active spectrum allocation. The proposed 5350-5470 MHz Radio Local Access Network (RLAN) service will severely limit science performed by the ESA Sentinel 1 satellite and the Canadian Radarsat-2 and RadarSat Constellation Mission (RCM) constellations. The broad-band, noise-like nature of RLAN emitters is difficult or impossible to mitigate.

FINDING: RFI has not been a significant impediment to planetary radar astronomy observations to date. However, as bandwidth requirements increase due to the need to image near-Earth asteroids at high spatial resolution, RFI could pose a significant problem in the future. To facilitate high spatial resolution imaging of small near-Earth asteroids, frequency assignments with bandwidths of 60 MHz to 120 MHz are required. The NASA JPL Goldstone radar currently has an assignment of 200 MHz centered at 8.600 GHz.

Operational Restrictions

Active sensors emit radiation and thus have the potential to interfere with other services that share the band. National and international regulatory bodies have placed geographic, power, and waveform restrictions on science systems that may result in a significant loss of data coverage or quality.

FINDING: In several cases, transmit restrictions imposed on active science sensors have significantly impeded the ability to collect the desired science data (as in the operational restrictions imposed on the ESA's Biological Investigations of Marine Antarctic Systems and Stocks [BIOMASS] mission), degraded the science data (an example being the deep spectral waveform notches required on the GeoSAR sensor flown on aircraft), or significantly driven up costs (as for the NASA Soil Moisture Active-Passive mission). Conservative interference standards in some bands can make science operations difficult. Restrictions imposed in the lower frequency UHF- and L bands are increasing with time.

FINDING: There are multiple bands allocated to Earth-Exploration Satellite Service-Active where only portions of the band are being used or that are not being used at all. With constant pressure to accommodate new services, it may be more difficult to establish new science in these bands in the future.

RECOMMENDED ACTIONS FOR FEDERAL AGENCIES

Quantifying Interference

One of the difficulties with characterizing the impact of RFI on active remote sensing space instruments is the incompleteness of information regarding current emitters worldwide, as well as the evolving nature of the RFI environment over time. This makes it very difficult to accurately evaluate how a given active sensor may be impacted by RFI, how the RFI might be mitigated, and how the spectrum might be shared. Mitigation techniques are most effective when the RFI environment is clearly understood prior to sensor deployment, flight, or launch, as not all interference can be removed in post-processing.

RECOMMENDATION: NASA should lead an effort to significantly improve characterization of the RFI environment that affects active science measurements. The effort could be coordinated by the Office of Science and Technology Policy. This should include the use of: 1) modeling, 2) dedicated ground-based and airborne characterization campaigns, and 3) data mining of currently operating science sensors. To the extent possible, this effort should be a collaborative one with other space and science agencies of the world.

RECOMMENDATION: NASA should lead a community effort to construct a set of metrics that relate to the various RFI environments encountered and the associated degradation in science performance for each major class of instruments employed in active remote sensing.

Facilitating Spectrum Sharing

The science community has employed a variety of unilateral and cooperative RFI mitigation methods to protect their sensors from damage or to improve science performance including receiver protection, out-of-band filtering, geographic avoidance, frequency avoidance, RFI detection, RFI removal, and cooperative operation. Current RFI mitigation techniques work best for interfering signals that have sparse spectral or temporal occupancy, which means active remote sensing is able to share more effectively with some services than with others depending on the nature of the interfering signal. Cooperative mitigation is limited primarily by the management issues inherent to the process.

RECOMMENDATION: Radar systems meeting specific criteria for pulse repetition, maximum pulse width, and duty cycle should be permitted by the FCC (Federal Communications Commission) or the NTIA (National Telecommunications and Information Administration) to operate as secondary users in communications bands, where minimal interference to the communications operations would be expected to occur.

RECOMMENDATION: The Office of Science and Technology Policy should adjudicate the possibility of time and frequency sharing between ESA BIOMASS and the DoD's Space Object Tracking Radar (SOTR) system.

FINDING: From the perspective of efficient spectrum usage, the active sensing community would benefit from the consolidation of the L-, C-, and S-band radar assets of NOAA and the FAA to a single multi-function radar at S-band, as proposed by the Multifunction Phased Array Radar program.

RECOMMENDATION: The committee recommends an investigation of spatial frequency re-use techniques (e.g. 7-to-1 spatial frequency saving) to reduce the total S-band spectrum requirements. The existing L-band spectrum should be maintained for earth imaging radar use only.

Recommended Changes in Spectrum Allocation

FINDING AND RECOMMENDATION: Coastal ocean dynamics applications radar (CODAR) would benefit from allocated bandwidths larger than 25 kHz near 4.438-4.488 MHz. The FCC should reinstate an experimental licensing process for CODAR to allow for future engineering research advances and exploratory science advances.

RECOMMENDATION: If deemed worthwhile by the astronomy community, and if the NSF considers it appropriate, the NSF should seek frequency assignments in the relevant bands for the proposed Green Bank and upgraded Arecibo radar systems to facilitate high spatial resolution imaging of small near-Earth asteroids.

RECOMMENDATION: Given the importance of the educational CubeSat program for the development of the aerospace workforce, and for the development of small satellite technology, the NSF, NASA, the FCC, and the NTIA should undertake a concerted and coordinated effort to eliminate impediments in the spectrum allocation process that are currently impeding the success of educational CubeSats.

Determining Future Spectrum Needs

RECOMMENDATION: NASA and the NSF should conduct a formal survey of the space physics research community to determine future spectrum needs.

RECOMMENDATION: NOAA should conduct a full assessment of the recent World Radiocommunication Conference (WRC) 2012 results regarding ground-based high-frequency radars to ensure that the planned build-out needs of the U.S. high-frequency over-the-horizon radar observing system can be adequately met.

RECOMMENDED ACTIONS FOR THE SCIENCE COMMUNITY

Merit alone will not assure that the spectrum required is available for the scientific community. Scientific interests must be actively engaged in the spectrum allocation and assignment process to assure that science needs are met. This will require ongoing efforts to make more information available about the value of active remote sensing and ensure active remote sensing is balanced with competing interests in regulatory processes.

RECOMMENDATION: The science community should increase its participation in the International Telecommunications Union (ITU), the NTIA, and the FCC spectrum management processes. This includes close monitoring of all spectrum management issues to provide early warning for areas of concern. It also requires regular filings in regulatory proceedings and meetings with decision makers. This will build credibility for the science community and ensure a seat at the table for spectrum-related decision making that impacts the science community.

RECOMMENDATION: For the spectrum management process to be effective, the science community, NASA, NOAA, NSF, and the DoD should also articulate the value of the science-based uses of radiofrequency spectrum. Such value will include both economic values, through enabling commerce or reducing the adverse economic impacts of natural phenomenon, and noneconomic values that come from science research.

RECOMMENDATION: The next decadal surveys in solar and space physics and Earth science should address the future spectrum needs for their communities.

POSSIBLE ACTIONS FOR THE TELECOMMUNICATIONS INDUSTRY

FINDING: The use of millimeter-wave frequencies for short-wave femtocell-sized communications would significantly increase network capacity by an order of magnitude, thereby reducing pressure on the spectrum and therefore on the active remote sensing users, as well.

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