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Spectrum Management and Its Importance for Microwave Remote Sensing

Fair and efficient management of the radio-frequency (RF) spectrum as used by different scientific and commercial services is becoming more and more challenging, and this can have a considerable impact on microwave remote sensing. Here, we provide an overview of those spectrum management aspects relevant to the remote-sensing community, along with an introduction to the actors and processes involved in spectrum regulation, including the World Radiocommunication Conference (WRC).

We also include a brief discussion regarding the issues currently being considered for the next WRC in 2019 that might have an impact on remote-sensing services. The objectives and activities of the IEEE Geoscience and Remote Sensing Society's (GRSS's) Frequency Allocation and Remote Sensing Technical Committee (FARS-TC) provides a way for anyone involved in remote sensing, from mission managers to researchers, to understand and participate in this complex regulatory process.

ALLOCATING SPECTRUM TO AVOID RADIO-FREQUENCY INTERFERENCE

Advances in technology and the growth of new commercial services in recent years have significantly increased spectrum demand, particularly in the RFs used by microwave remote sensing. In some cases, this has led to negative effects, especially in the form of measurements corruption from unwanted artificial emissions, also known as *RF interference* (*RFI*) [1]–[3]. For this reason, it is essential that remote-sensing scientists and engineers understand the role and workings of spectrum management, defined as the process of regulating and coordinating the use of the RF spectrum for different services. The most important function of spectrum management is frequency allocation, which involves designating portions of the spectrum for specified uses based on international agreements, with the goal of avoiding unregulated utilization and minimizing interference between different services. This process is controlled by various governmental and international organizations, with the International Telecommunication Union (ITU), in particular, at the highest level, as explained in the following section.

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THE INTERNATIONAL TELECOMMUNICATION UNION

The ITU is a specialized agency of the United Nations responsible for matters relevant to telecommunication technology, operations, and services throughout the world. It oversees the shared global use of the RF spectrum, promotes international cooperation in assigning satellite orbits, works to improve telecommunication infrastructure in the developing world, and assists in the creation and coordination of worldwide technical standards [4].

The ITU is structured in three sectors with different responsibilities. They are

- radiocommunication (the ITU-R sector), which ensures optimal, fair, and rational use of the global RF spectrum (Article 12 of [4])
- telecommunication standardization (the ITU-T sector), which formulates recommendations for telecommunication standards (Article 17 of [4])
- development (the ITU-D sector), which fosters the spread of equitable, sustainable, and affordable access to information and communication technologies (Article 21 of [4]).

The ITU membership is composed of sovereign countries, known as *administrations*, which may join the organization as member states, and nonvoting sector members, which can be academic and research institutions, international and regional telecommunication organizations, and private entities, such as wireless carriers and equipment manufacturers. There are

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currently 193 ITU member states and almost 800 sector members. ITU member states are organized into regional groups [5] as follows:

- Asia-Pacific Telecommunity (APT)
- Arab Spectrum Management Group (ASMG)
- African Telecommunications Union (ATU)
- European Conference of Postal and Telecommunications Administrations (CEPT)
- Inter-American Telecommunication Commission (CITEL)
- Regional Commonwealth in the Field of Communications (RCC).

THE ITU RADIOCOMMUNICATION SECTOR

ITU-R plays a vital role in the global management of the RF spectrum and satellite orbits, which are limited and increasingly scarce resources. Its mission is to "ensure the rational, equitable, efficient, and economical use of the radio frequencies by all radiocommunication services," including those using satellite orbits, and to carry out studies and approve recommendations on radiocommunication matters [4].

RF USE IS GOVERNED BY RULES CONTAINED IN THE ITU RADIO REGULATIONS, WHICH COMPLEMENT THE ITU CONSTITUTION AND CONVENTION.

As stated under Article 12 ("Functions and Structure") of the ITU Constitution [4], the ITU-R pursues its technical scope through study groups, which produce the technical bases for decisions made at WRCs (see the section "The World Radiocommunication Conference and Its Preparation Process") and develop global standards (referred to as *recommendations*), reports, and handbooks on radiocommunication matters. Thousands of specialists from organizations and telecommunication industries participate in the work of the study groups, of which the ITU-R currently has the following six:

- Study Group 1 (SG-1) on spectrum management
- Study Group 3 (SG-3) on radiowave propagation
- Study Group 4 (SG-4) on satellite services
- Study Group 5 (SG-5) on terrestrial services
- Study Group 6 (SG-6) on broadcasting service
- Study Group 7 (SG-7) on science services.

Note that there is no Study Group 2. SG-7 deals with the following science services [2]:

- systems for space operation, space research, Earth exploration, and meteorology, including the related use of links in the intersatellite service
- systems for remote sensing, including passive and active sensing systems, operating on both ground- and space-based platforms
- radio astronomy and radar astronomy
- the dissemination, reception, and coordination of standard-frequency and time-signal services, including the application of satellite techniques, on a worldwide basis.

The technical activities of SG-7 are divided among four working parties, which perform studies on matters assigned to the study group:

- Working Party 7A (WP-7A): time signals and frequency standards emissions—systems and applications (terrestrial and satellite) for the dissemination of standard time and frequency signals
- Working Party 7B (WP-7B): space radiocommunication applications—systems for the transmission/reception of telecommand, tracking, and telemetry data for space operation, space research, Earth-exploration satellite, and meteorological satellite services
- Working Party 7C (WP-7C): remote-sensing systems—active and passive remote-sensing applications in the Earth-exploration satellite service (EESS) and systems for the meteorological aids (MetAids) service (see the following section for definitions), as well as ground-based passive sensors, space weather sensors, and space research sensors, including planetary sensors
- Working Party 7D (WP-7D): radio astronomy—radio astronomy and radar astronomy sensors, both Earth and space based, including the Space Very Long Baseline Interferometry network.

As indicated previously, WP-7C covers issues related to remote-sensing systems. Its activities are aimed at developing and maintaining ITU-R recommendations, reports, and handbooks relevant to remote sensing in Earth exploration and meteorological activities. These include assessing spectrum requirements and protection criteria for the services cited earlier and establishing sharing criteria with other services. The resulting RS Series ITU-R recommendations are of paramount importance to administrations, space agencies, and industry. In addition to spaceborne systems, WP-7C also considers ground-based and airborne passive sensors, their technical and operational characteristics, and their protection requirements, as they become increasingly important for observing and monitoring the Earth's environment.

In addition to these systems and applications, WP-7C is currently investigating the categorization of ground- and space-based space weather sensors, their corresponding frequency allocations, and their technical and operational characteristics and protection requirements. According to the World Meteorological Organization's definition, "space weather encompasses the conditions and processes occurring in space, including on the sun, in the magnetosphere, ionosphere, and thermosphere, which have the potential to affect the near-Earth environment" [12]. Figure 1 illustrates the ITU organizational structure and highlights the bodies relevant to remote sensing.

RADIOCOMMUNICATION SERVICES AND FREQUENCY ALLOCATIONS

RF use is governed by rules contained in the ITU Radio Regulations [6], which complement the ITU Constitution and Convention. The Radio Regulations constitute an international treaty that defines the use of the RF spectrum and the various radiocommunication services, which, according to Article 1.19 of the Radio Regulations, are services "involving the transmission, emission, and/or reception of radio waves for specific telecommunication purposes." Section III of Article 1 of the Radio Regulations provides the definitions of these radiocommunication services, which are listed in Table 1. The first column indicates the Radio Regulations article number where the service is defined. Note that radio astronomy is not a radiocommunication service per se but simply a service involving the use of radio waves, and it has been considered for this reason.

Some services are a subset of another service. For example, the land mobile service (LMS) in Article 1.26 is considered to be a branch of the mobile service (MS) defined in Article 1.24, which, in addition to the LMS, also encompasses the mobile maritime service (MMS) in Article 1.28 and the aeronautical mobile service (AMS) in Article 1.32. For many terrestrial radiocommunication services, there is also a parallel space radiocommunication service, as in the case of the broadcasting service (BS) and its parallel broadcasting-satellite service (BSS).

Further subsets of some of these internationally defined services are often created at the national level. For example, within the LMS, a country may choose to define such services as paging, dispatch of two-way radio service, cellular mobile telephone service, and trunked mobile radio service. Regardless of the terminology adopted in a given country, the use of the spectrum must adhere to the international definitions of radio services, with some specific exceptions that the ITU Radio Regulations allow for. In particular, the EESS is defined in Article 1.51 as the following:

a radiocommunication service between Earth stations and one or more space stations, which may include links between space stations, in which

- information relating to the characteristics of the Earth and its natural phenomena, including data relating to the state of the environment, is obtained from active sensors or passive sensors on Earth satellites
- similar information is collected from airborne or Earth-based platforms
- such information may be distributed to Earth stations within the system concerned
- platform interrogation may be included.

This service may also include feeder links necessary for its operation.

The particular use is denoted in parentheses and can be active or passive in the case of a sensor-acquiring measurements in that frequency and space-to-Earth or Earth-to-space in the case of a band used for data downlink/uplink: e.g., EESS (active), EESS (space-to-Earth), and so forth. Also important for remote sensing is the meteorological-satellite service defined in Article 1.52 as an EESS for meteorological purposes.

Frequency allocation is the designation of portions of the radio spectrum for use by specific radiocommunication services in accordance with international agreements based on technical characteristics and national needs. An allocation reserves a given frequency band for use by one or more radio communication services. National and international tables of frequency allocations contain lists of these frequency band designations. In addition to allocation, for coordination purposes, in Chapter I, Section II, the Radio Regulations define other two terms: *spectrum allotment* and *assignment*. Assignment is the authorization given by

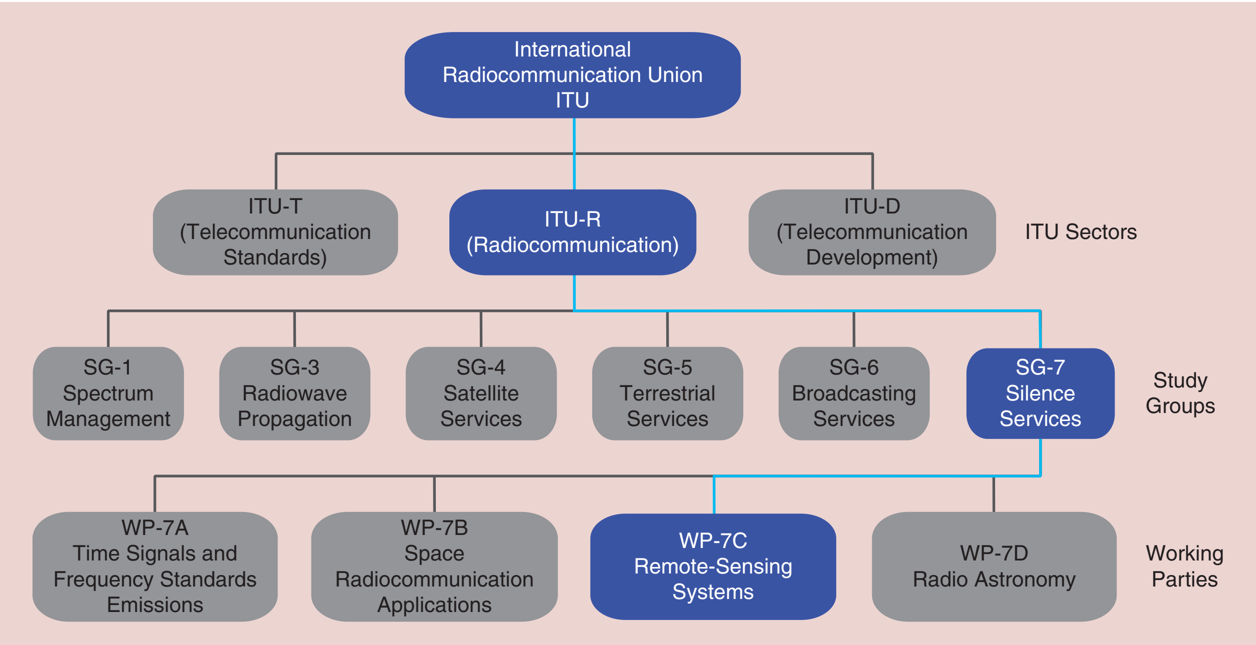

FIGURE 1. The structure of the ITU, with the bodies relevant to remote sensing highlighted in blue.

TABLE 1. THE RADIOCOMMUNICATION SERVICES.

ARTICLE NUMBER	NAME OF SERVICE	ABBREVIATION/ACRONYM
1.20	Fixed service	Fixed
1.21	Fixed-satellite service	FSS
1.22	Intersatellite service	ISS
1.23	Space operation service	SOS
1.24	Mobile service	MS
1.25	Mobile-satellite service	MSS
1.26	Land mobile service	LMS
1.27	Land mobile-satellite service	LMSS
1.28	Maritime mobile service	MMS
1.29	Maritime mobile-satellite service	MMSS
1.30	Port operations service	POS
1.31	Ship movement service	SMS
1.32	Aeronautical mobile service	AMS
1.33	Aeronautical mobile (R) service	AM(R)S
1.34	Aeronautical mobile (OR) service	AMS(OR)
1.35	Aeronautical mobile-satellite service	AMSS
1.36	Aeronautical mobile-satellite (R) service	AMS(R)S
1.37	Aeronautical mobile-satellite (OR) service	AMS(OR)S
1.38	Broadcasting service	BS
1.39	Broadcasting-satellite service	BSS
1.40	Radiodetermination service	RDS
1.41	Radiodetermination-satellite service	DRSS
1.42	Radionavigation service	RNS
1.43	Radionavigation-satellite service	RNSS
1.44	Maritime radionavigation service	MRNS
1.45	Maritime radionavigation-satellite service	MRNSS
1.46	Aeronautical radionavigation service	ARNS
1.47	Aeronautical radionavigation-satellite service	ARNSS
1.48	Radiolocation service	RLS
1.49	Radiolocation-satellite service	RLSS
1.50	Meteorological aids service	MetAids
1.51	Earth-exploration satellite service	EESS
1.52	Meteorological-satellite service	MetSat
1.53	Standard frequency and time signal service	SFTS
1.54	Standard frequency and time signal-satellite service	SFTSS
1.55	Space research service	SRS
1.56	Amateur service	ARS
1.57	Amateur-satellite service	ARSS
1.58	Radio astronomy service	RAS
1.59	Safety service	None
1.60	Special service	None

an administration for the use of an RF or channel under specified conditions; the administration is responsible for the RFI management pertaining to each given assignment. In other words, before it is allowed to use a specific band, a radio station needs both the spectrum allocation and a frequency assignment. An allocated band can be further divided into allotments or channels that designate its use in one or more geographic regions and under certain conditions. On a national level, the allotment refers to the assignment of a block of spectrum to a licensee who makes specific assignments to stations within that frequency block.

Article 5 of the Radio Regulations contains the "Table of Frequencies." These are the frequency allocations agreed upon at the international level, which cover the part of the electromagnetic spectrum from 9 kHz to 275 GHz. For the purpose of spectrum allocation, the world is divided into three regions, as shown in Figure 2. Each ITU region has its own set of frequency allocations, which may or not coincide with those of the other regions for a particular frequency band.

Figure 3 provides an example of the "Table of Frequencies" for the 10–10.7-GHz band. The table includes a column for each ITU region. If two or more regions share exactly the same allocations, the corresponding columns are merged together. In each cell, the frequency interval is in a bold font, followed by the name of the services. Services with primary allocations are in capital letters, while secondary allocations are lowercase. Footnotes can be added to indicate regional differences or other particular cases or exceptions.

THE WORLD RADIOCOMMUNICATION CONFERENCE AND ITS PREPARATION PROCESS

Every three to four years, the ITU organizes a WRC to review and, if necessary, revise the Radio Regulations [7]. In particular, under the terms of the ITU Constitution, the WRC can

- change the Radio Regulations and any associated frequency plans
- address any radiocommunication matters that have worldwide effects
- instruct the Radio Regulations Board and the Radiocommunication Bureau and review their activities
- adopt new resolutions
- decide what areas the Radiocommunication Assembly and its study groups should consider in preparation for future WRCs.

Simply put, this means that a WRC decides what and how spectrum and satellite orbits can be used by all radiocommunication services, including remote-sensing systems and International Mobile Telecommunications (IMT) standards.

Revisions are made on the basis of an agenda determined by the ITU Council. The general scope of the agenda is established four to six years in advance of each conference, while the final agenda is based on the recommendations made during the preceding WRC and finally approved by the ITU Council two years before the conference, with the agreement of a majority of member states. Preparation for the WRC involves the ITU study groups, the six ITU regional groups (the APT, ASMG, ATU, CEPT, CITEL, and RCC), individual administrations, and private entities. The simplified diagram in Figure 4 summarizes the different stages.

The process starts immediately after a WRC ends, when the agenda for the following WRC is set. The first Conference Preparatory Meeting (CPM) directly follows the WRC to organize and coordinate the work of the ITU-R study groups and prepare a draft structure for the CPM report, based on the agenda for the following two WRCs and on any directives from the previous WRC. The second CPM is held approximately six months before the WRC to collect the contributions from the ITU study groups, regional groups, member states, and sector members and prepare a final report that will play a key role in the decisions made at the WRC.

Each of the six regional groups organizes its own CPM to develop and consolidate the positions within that region on the various WRC agenda items (AIs). In each of these preparatory meetings, the discussions are also split among the different study groups. After the work is allocated, all contributions are gathered, and joint proposals are gradually developed. A similar process occurs in preparations at the national level to develop the positions of the member

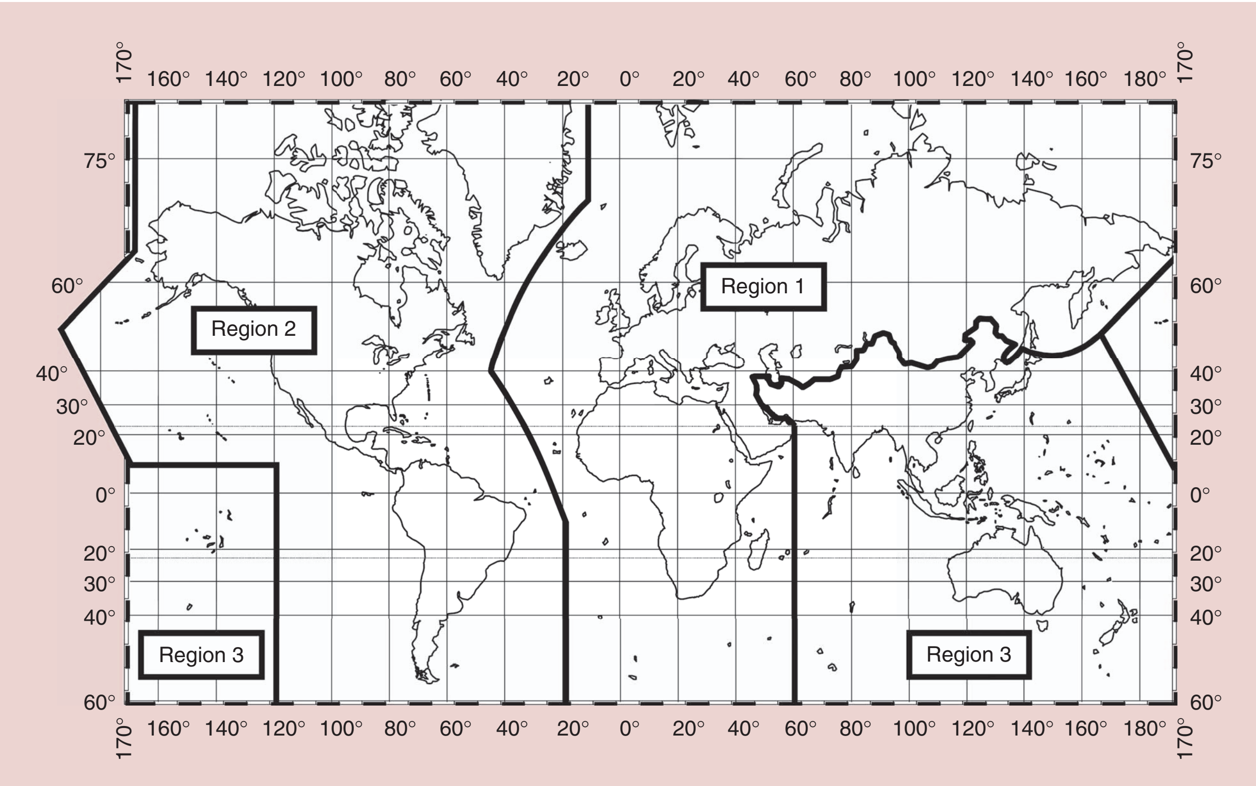

FIGURE 2. The ITU regions (adapted from [6]).

10–10.7 GHz

Allocation to Services		
Region 1	Region 2	Region 3
10–10.4 Earth-Exploration Satellite (Active) 5.474A 5.474B 5.474C Fixed Mobile Radiolocation Amateur 5.474D 5.479	10–10.4 Earth-Exploration Satellite (Active) 5.474A 5.474B 5.474C Radiolocation Amateur 5.474D 5.479 5.480	10–10.4 Earth-Exploration Satellite (Active) 5.474A 5.474B 5.474C Fixed Mobile Radiolocation Amateur 5.474D 5.479
10.4–10.45 Fixed Mobile Radiolocation Amateur	10.4–10.45 Radiolocation Amateur 5.480	10.4–10.45 Fixed Mobile Radiolocation Amateur
10.45–10.5	Radiolocation Amateur Amateur-Satellite 5.481	
10.5–10.55 Fixed Mobile Radiolocation	10.5–10.55 Fixed Mobile Radiolocation	
10.55–10.6	Fixed Mobile Except Aeronautical Mobile Radiolocation	
10.6–10.68	Earth-Exploration Satellite (Passive) Fixed Mobile Except Aeronautical Mobile Radio Astronomy Space Research (Passive) Radiolocation 5.149 5.482 5.482A	
10.68–10.7	Earth-Exploration Satellite (Passive) Radio Astronomy Space Research (Passive) 5.340 5.483	

Primary Allocation · Secondary Allocation · Footnotes

FIGURE 3. An example of “Table of Frequencies” from the Radio Regulations.

states within their territory. Participation in these meetings by scientific communities and the private sector is encouraged so that all possible information may be gathered and all interests represented.

In addition, the ITU Radiocommunication Bureau organizes annual ITU Interregional Workshops to present the ongoing work of the ITU-R preparatory studies and other information on the regional preparations. These meetings provide participants with the opportunity to exchange views and gain a better understanding of the draft's common perspectives, positions, and proposals as they involve the concerned entities. Finally, the Radio Regulations are updated based on the agreements made at the WRC, an agenda for the next WRC is established, and the process starts again.

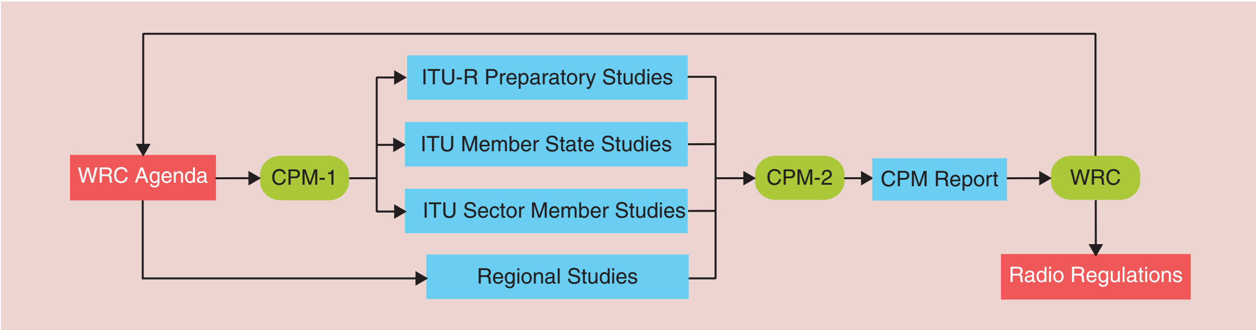

FIGURE 4. A simplified flowchart of the WRC preparation process.

The most recent WRC took place in Geneva, Switzerland, on 2–27 November 2015, and the first CPM was also held there, 30 November–1 December 2015. The second CPM is planned for 18–28 February 2019, also in Geneva. The next WRC, referred to as WRC-19, will be held in Sharm el Sheikh, Egypt, on 28 October–22 November 2019.

WORLD RADIOCOMMUNICATION CONFERENCE 2019 AGENDA ITEMS

As mentioned previously, the preliminary agenda was established in advance during WRC 2015 and finalized in 2017, two years before WRC-19. Table 2 provides a list of the AIs that have the greatest potential significance for microwave remote sensing [8]–[10]. As the table indicates, several frequency ranges presently used by passive and active remote-sensing services will be under discussion at WRC-19 and potentially affected by the decisions made there. For instance, AI 1.5 examines the possibility of using the frequency band 17.7–19.7 GHz for downlinks by Earth Stations in Motion (ESIM) systems communicating with geostationary space stations in the fixed-satellite service (FSS). The passive use of the 18.6–18.8 GHz band, fundamental for water-vapor measurement retrievals, could be adversely impacted.

Another example is AI 1.6, which studies the possibility of allowing nongeostationary orbit (NGSO) FSS satellite systems to operate uplinks in the 37.5–39.5 GHz and 39.5–42.5 GHz bands and downlinks in the 47.2–50.2 GHz and 50.4–51.4 GHz bands. Some of these bands are used for data communication and passive remote sensing of several Earth parameter observations.

AI 1.13 aims to identify considerable new spectrum for the future development of IMT and pursues additional allocations for MS on a primary basis in parts of the frequency range between 24.25 and 86 GHz. Under consideration are current primary MS allocations, namely, the bands 24.25–27.5, 37–40.5, 42.5–43.5, 45.5–47, 47.2–50.2, 50.4–52.6, 66–76,

TABLE 2. THE WRC-19 AIs OF RELEVANCE TO MICROWAVE REMOTE SENSING.

AI	SUMMARY
1.2	To consider in-band power limits for Earth stations operating under MSS, MetSat, and EESS in the 401–403-MHz band for data collection systems and the 399.9–400.05-MHz band for MSS
1.3	Possible upgrade to primary status for MetSat (space-to-Earth) allocation and a new primary EESS (space-to-Earth) allocation at the 460–470-MHz band
1.5	To consider the use of the frequency bands 17.7–19.7 GHz (space-to-Earth) and 27.5–29.5 GHz (Earth-to-space) by ESIM systems communicating with geostationary space stations in the FSS
1.6	To consider the development of a regulatory framework for NGSO FSS satellite systems that may operate in the frequency bands 37.5–39.5 GHz (space-to-Earth), 39.5–42.5 GHz (space-to-Earth), 47.2–50.2 GHz (Earth-to-space), and 50.4–51.4 GHz (Earth-to-space)
1.7	To study the spectrum needs for telemetry, tracking, and command in the SOS for NGSO satellites with short-duration missions, to assess the suitability of existing allocations to the SOS and, if necessary, to consider new allocations
1.8	To consider possible regulatory actions within the 156–162.05-MHz band to protect Global Maritime Distress Safety Systems (GMDSS) modernization and support the introduction of additional satellite systems into the GMDSS
1.13	To consider the identification of frequency bands on a primary basis in portion(s) of the frequency range between 24.25 and 86 GHz for the future development of IMT for 2020 and beyond
1.14	To consider appropriate regulatory actions for HAPS systems within existing FSS allocations
1.15	To consider the identification of frequency bands for use by administrations for the land-mobile and fixed services applications operating in the frequency range 275–450 GHz
1.16	To consider issues related to WAS/RLANs in the frequency bands between 5,150 MHz and 5,925 MHz and to take appropriate regulatory actions, including additional spectrum allocations to the mobile service

and 81–86 GHz. In addition, the frequency bands 31.8–33.4, 40.5–42.5, and 47–47.2 GHz may be considered for new allocations to the mobile services on a primary basis. Many of these bands are used by science services to measure weather and climate variables with active and passive sensors onboard satellites. Therefore, there is a potential for a harmful impact on these scientific missions.

Another concern for remote sensing is AI 1.14, which examines enabling access to broadband applications delivered by high-altitude platform stations (HAPS). HAPS would provide wireless broadband deployment in remote areas, including mountainous, coastal, and sandy desert regions. The frequencies considered on a global level are 38–39.5 GHz and, on a regional level, 21.4–22 and 24.25–27.5 GHz. Again, these latter bands are used for many remote-sensing observations of Earth variables and scientific studies.

Similarly, AI 1.15 considers identification of the land-mobile and fixed-service applications operating in the frequency range of 275–450 GHz for use by administrations. Numerous passive sensor missions use frequencies within this spectrum range.

In addition, AI 1.16 seeks to identify potential wireless access system/radio local area network (WAS/RLAN) mitigation techniques to facilitate sharing with incumbent systems in the 5,150–5,350, 5,350–5,470, 5,725–5,850, and 5,850–5,925 MHz frequency bands. Numerous active EESS and SRS satellites and airborne missions use the 5,300–5,500 MHz band, which could be severely impacted.

In sharing the spectrum, one of the main challenges for passive remote sensors is their vulnerability to RFI because of their inherently high sensitivity (given that they are designed to measure noise-like signals). For active EESS sensors, one of the main challenges is that they cover vast regions of the Earth's surface, so the aggregate effect of spectrum sharing in urban areas can have a detrimental effect on their measurements and render them useless.

THE FREQUENCY ALLOCATIONS AND REMOTE SENSING TECHNICAL COMMITTEE'S ROLE AND ACTIVITIES IN SPECTRUM MANAGEMENT

The FARS-TC was established by the GRSS to defend the interests of the remote-sensing community in matters relevant to frequency allocations. Its membership is composed of scientists and engineers working in remote sensing at a variety of institutions worldwide. The technical committee is among the international entities that help advocate for and create awareness of the importance of the RF spectrum regulation process in efficiently sharing this limited resource for society's benefit. It cooperates with various organizations, such as the Space Frequency Coordination Group at the international level and the Committee on Radio Frequencies of the National Academy of Sciences at the U.S. level, on spectrum management issues relevant to remote sensing. In the spectrum management community, it is in a position to represent remote-sensing scientists and engineers more independently than administrations, which that need to consider all their national interests.

In addition, the FARS-TC promotes the development of RFI detection and mitigation technology through organizing tutorials, workshops, and conference technical sessions and by fostering the exchange of information between researchers in different fields, such as remote sensing, radio astronomy, and telecommunications, with the common goal of minimizing harmful interference between systems. More information on the technical committee can be found at [11]. Anyone interested in joining, either to contribute to or stay informed on these issues, can sign up on the FARS-TC webpage.

AUTHOR INFORMATION

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Yan Soldo (yan.soldo@nasa.gov) received his B.S. degree in aerospace engineering from the Politecnico, Turin, Italy, in 2007. He was selected for a joint double-degree program with the Politecnico and Institut supérieur de l'aéronautique et de l'espace-École nationale supérieure de l'aéronautique et de l'espace in Toulouse, France, which granted him two M.S. degrees in aerospace engineering in 2010. In 2010, he was funded by the Centre National d'Etudes Spatiales to pursue a Ph.D. degree in microwave remote sensing at the Centre d'etudes spatiales de la biosphère research facility. His contributions are in the fields of signal processing, data simulation, and radio-frequency interference characterization and mitigation applied to the soil moisture ocean salinity (SMOS) and SMOS-Next missions; he completed his Ph.D. degree in 2013. He is currently with the Earth Science Division, U.S. National Aeronautics and Space Administration Goddard Space Flight Center, Greenbelt, Maryland, where he continues his work on microwave remote sensing for the Aquarius and Soil Moisture Active/Passive missions. He has cochaired the IEEE Geoscience and Remote Sensing Society Frequency Allocations in Remote Sensing Technical Committee since 2017. He is a Member of the IEEE.

Sandra Cruz-Pol (cruzpol@ece.uprm.edu) received her B.S. degree from the University of Puerto Rico at Mayagüez (UPRM), her M.S. degree from the University of Massachusetts, and her Ph.D. degree in electrical engineering from Pennsylvania State University, working with passive and active satellite sensors and studying atmospheric gases and sea-surface emissivity; all three degrees were awarded summa cum laude. She joined the Electrical and Computer Engineering Department at UPRM in 1991, where she is now a full professor. She is part of the U.S. National Academies of Science (NAS) Committee on Radio Frequencies and is also an appointed member of the NAS Active Spectrum Study. She was the program director for the Enhancing Access to the Radio Spectrum program and spectrum manager at the U.S. National Science Foundation (NSF). She was appointed by the NSF to serve as a member of the U.S. Delegation for Spectrum Management to the International Telecommunications Union in Geneva, Switzerland, and was the NSF representative for the Interdepartment Radio Advisory Committee at the U.S. National Telecommunications and Information Administration and for other subcommittees, including the Frequency Assignment subcommittee. While with the NSF, she was selected as the federal liaison for the U.S. National Committee for the International Union for Radio Science. Her research interests include microwave sensors, weather radars, and climate monitoring. She received the NASA Faculty Award for research in 2002. She was associate editor of "University Affairs" for the *IEEE Geoscience and Remote Sensing Society Newsletter* for five years, and she is a Senior Member of the IEEE.

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