6G Spectrum Policy Issues above 100 GHz

Michael J. Marcus

As 5G rollout is underway in many countries, R&D is also underway on its successor 6G and along with deliberations in International Telecommunication Union — Radiocommunication Standardization Sector (ITU-R) Working Party 5D (WP 5D) [1]. 6G will likely use both the existing approximately 50 5G frequency bands that range from 617 MHz to 48.2 GHz, not all of which are available in every country, as well as possible new bands above 100 GHz that have no commercial use at this time [2]. The bands above 100 GHz are attractive for high communications bit rate links because they potentially offer much greater bandwidths than the maximum 400 MHz contiguous bandwidth in any of the existing 5G bands. While bonding nonadjacent bands together for high bit rates has been done at lower bands, it is unclear yet whether this is practical for bandwidths greater than 400 MHz at frequencies above 100 GHz where there are large blocks of unused spectrum at present.

There is interest in possibly using contiguous bandwidths, in the multiple GHz range, for 6G above 100 GHz. This article explores the spectrum policy issue involved in such possible uses as well as technical and policy problems that would have to be solved. In particular, it points out that if large contiguous bands will be needed for 6G use, spectrum policy issues have to be addressed in a timely way in parallel with 6G R&D.

While spectrum policy issues are not as immutable as physical limits based on Maxwell's Equation, they can and do change over time as the spectrum policy community understands better new wireless technologies, societal needs for wireless services, the physics of bands that are at the edge of presently used spectrum, and innovative approaches to let disparate spectrum uses share the same and/or nearby bands. While some spectrum policy issues may be resolved in the matter of a year or so, issues that are rigidly specified in the ITU Radio Regulations (RRs) [3], a treaty of obligation of ITU's 193 nation states, can take up to a decade to resolve. Thus, it is important to identify spectrum policy issues early in the development of new wireless technologies, either to address how they limit technical options or to plan to update them on realistic schedules.

EHF spectrum, especially in frequencies above 100 GHz, differs from lower bands in the presence of many passive bands, including 10 bands in 100–275 GHz where "all emissions are prohibited" by the terms of ITU RR 5.340. These passive bands serve many very important functions for both radio astronomy and environmental sensing [4]. For example, passive satellites in some of these bands provide key information for weather forecasting that enhances public safety throughout the world. They also provide key information on the distribution of molecules throughout the atmosphere that may be causing climate change. Figures 1 and 2 compare passive spectrum allocations in EHF with those at lower lower bands.

In addition to the EHF RR 5.340 bands with total prohibitions of cochannel use, there are also other bands where there are passive allocations with some sharing for active services. The largest contiguous blocks of spectrum below 275 GHz where all allocations present end, which can be used for fixed and/or mobile use without sharing restrictions, are 12.5 GHz in 151.5–164 GHz (in the case of under 200 GHz) and 23 GHz in 252–275 GHz (considering all frequencies up to 275 GHz).

Fortunately, when most of the present allocations above 100 GHz were adopted at the 2000 ITU World Radio Conference (WRC-2000) resulting from proposals from both the United States and CEPT (the union of European spectrum regulatory agencies), there was uncertainty about the need to totally prohibit sharing of these bands in view of the fact that the physics in this part of the spectrum differs greatly from lower regions. At that time, both the United States [5] and CEPT [6] separately proposed ITU-R studies of sharing feasibility and left the door open for future sharing. These two proposals were merged, resulting in WRC-2000 Resolution 731 (Res. 731), which asks ITU-R to "continue its studies to determine if and under what conditions sharing is possible between active and passive services in the bands above 71 GHz" [7]. Res. 731 cites several ITU-R recommendations that specify quantitative limits for the maximum acceptable interference a protected passive system can receive. While this resolution was updated at WRC-19 with additional studies above 275 GHz, the original provisions for 71-275 GHz remain unchanged [8]. While the terms of Res. 731 protect both passive environmental satellites and radio astronomy observatories, the protection of radio astronomy is relatively easy since above 100 GHz atmospheric absorption of RF by molecules makes siting impractical in an area with moderate to high humidity, and high altitudes also are very desirable due to lower attenuation of distant signals by the column of air above the antenna. Thus, observatories generally are in high arid remote areas and can be protected by quiet zones that take advantage of terrain blocking [9].

Protecting passive satellites is much more complex due to the fact that their antennas face either the surface of the Earth or parts of the atmosphere near the surface, and the satellites cover the whole surface continuously throughout the day, so any terrestrial emitter is a potential interference threat unless countermeasures are taken. In general, wireless telecommunications systems involve paths that are at low or negative elevation angles and have no need to illuminate high elevation angles. Above 100 GHz high elevation angle paths result in path losses to satellites often greater than 1000 dB, much greater than any terrestrial paths or even satellite paths at lower frequencies, due to atmospheric absorption [10]. Thus, the desired low/negative angle emissions of telecommunications transmitters are not an interference threat to passive satellites; the threat comes from high elevation angle emissions that in economic terms is an "externality" — an unintended by-product that causes harm to other societal or economic entities but no direct benefit to the producer of the externality [11].

But there are potential solutions to design 6G fixed or mobile radio links in ways that would limit signals' strengths to passive systems to the values given in Res. 731. Three possible approaches are:

1. Suppress antenna sidelobes of 6G links in bands with passive allocations to levels much lower than has been needed to protect other terrestrial systems.
2. Use multiple-input multiple-output (MIMO)-like transmit antennas that can *both* adjust antenna elements to maximize power transfer to receiver antenna and *also* minimize power in the direction of passive satellites passing over the area with known orbits.
3. In the case of backhaul links, use a mesh network and reroute traffic on the network to minimize power transfer to satellites passing over the area.

None of these are off-the-shelf solutions, and the latter two would be more practical if passive satellite orbit parameters were standardized to a degree. While the orbits are not gen-

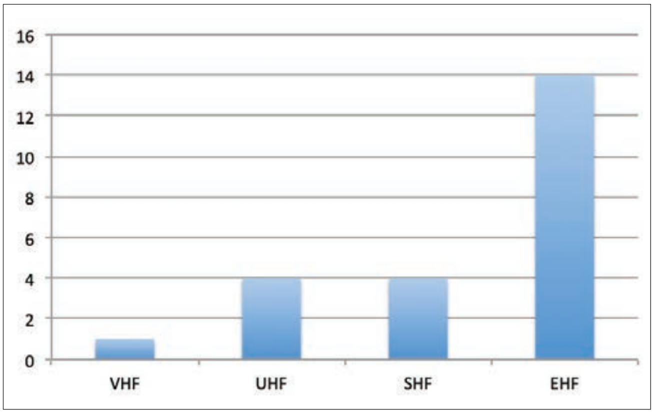

FIGURE 1. Number of passive allocations subject to RR 5.340.

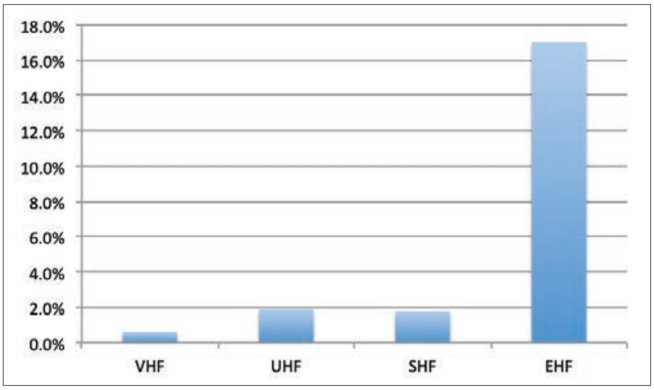

FIGURE 2. Fraction of band allocated to passive bands subject to RR 5.340.

erally standardized now, one of the provisions of Res. 731 states that "to the extent practicable, the burden of sharing among active and passive services should be equitably distributed among the services to which allocations are made." One approach to "burden sharing" might be to standardize passive satellite orbits somewhat in the future.

While it may be possible to share some of the passive bands above 71 GHz to achieve greater than 12.5 or 23 GHz contiguous bandwidth, achieving that will require parallel efforts in both R&D of sharing mechanisms and achieving an ITU-R recommendation to a future WRC, now held every four years. At present ITU-R has decided that this issue must involve three different ITU-R study groups, so the ITU-R deliberations could be time consuming.

Generally, WRC agendas are determined at a previous WRC, so it is impossible to resolve this issue at the next conference, WRC-23, and difficult now to even get it on the agenda for WRC-27. What all of this means is that the 6G community has to decide soon if they need contiguous bandwidth greater than 12.5 or 23 GHz and, if they do, start proceeding on both R&D for showing the sharing is practical as well as ITU-R deliberations on Res. 731 spectrum sharing issues in anticipation of changing RR 5.340 to allow carefully controlled spectrum sharing with passive satellites above 100 GHz.

References

[1] A. Weissberger, "Development of 'IMT Vision for 2030 and Beyond' from ITU-R WP 5D," *IEEE ComSoc Technology Blog*, June 15, 2021; https://techblog.comsoc.org/2021/06/15/development-of-imt-vision-for-2030-and-beyond-from-itu-r-wp-5d/.

[2] M. J. Marcus, "Progress in Opening Access to Spectrum above 100 GHz," *IEEE Wireless Commun.*, vol. 26, no. 2, Apr. 2019, pp. 2–3. DOI: 10.1109/MWC.2019.8700131.

[3] ITU Radio Regulations 2020; https://www.itu.int/hub/publication/R-REG-RR-2020/.

[4] Committee on Radio Frequencies, National Academy of Science (USA), "Spectrum Management for Science in the 21st Century, 2010; https://www.nap.edu/catalog/12800/spectrum-management-for-science-in-the-21st-century.

[5] USA Proposals for WRC-2000; https://search.itu.int/history/HistoryDigitalCollectionDocLibrary/4.126.51.en.101.pdf at p. 646.

[6] European Common Proposals for WRC-2000; https://search.itu.int/history/HistoryDigitalCollectionDocLibrary/4.126.51.en.101.pdf at p. 1121.

[7] ITU WRC-2000, Resolution 731; https://www.itu.int/net/ITU-R/conferences/docs/ties/res-731-en.pdf.

[8] ITU WRC-2019, Resolution 731, REV.WRC-19; https://www.itu.int/dms_pub/itu-r/oth/0C/0A/R0C0A00000F00149PDFE.pdf.

[9] ITU-R Rec. RA.1031, "Protection of the Radio Astronomy Service in Frequency Bands Shared with Active Services," 2021; https://www.itu.int/rec/R-REC-RA.1031-3-202112-I/en.

[10] ITU-R Rec. P.676, "Attenuation by Atmospheric Gases and Related Effects," 2019; https://www.itu.int/rec/R-REC-P.676/en.

[11] T. K. Forde and L. E. Doyle, "Exclusivity, Externalities & Easements: Dynamic Spectrum Access and Coasean Bargaining," *2007 2nd IEEE Int'l. Symp. New Frontiers in Dynamic Spectrum Access Networks*, 2007, pp. 303–15; https://www.imf.org/external/pubs/ft/fandd/basics/external.htm. DOI: 10.1109/DYSPAN.2007.48.

Biography

MICHAEL J. MARCUS [S'66, M'72, SM'01, F'04] (mjmarcus@marcus-spectrum.com) is a principal research scientist, Institute for the Wireless Internet of Things, an adjunct professor of ECE at Northeastern University, and director of Marcus Spectrum Solutions. He retired from the Federal Communications Commission in 2004 after nearly 25 years in senior spectrum policy positions. While at FCC, he proposed and directed the policy developments that resulted in the bands used by Wi-Fi, Bluetooth, and licensed and unlicensed millimeter-wave systems above 59 GHz. He was an exchange visitor from FCC to the Japanese spectrum regulator (now MIC), and has been a consultant to the European Commission and the Singapore regulator (now IMDA). During 2012–2013 he was Chair of the IEEE-USA Committee on Communication Policy and is now its Vice Chair for spectrum policy. In 2013, he was awarded the IEEE ComSoc Award for Public Service in the Field of Telecommunications "for pioneering spectrum policy initiatives that created modern unlicensed spectrum bands for applications that have changed our world." He received S.B. and Sc.D. degrees in electrical engineering from MIT.