Possible Active/Passive Spectrum Sharing in the 100–275 GHz Band Pursuant to WRC-2000 Resolution 731

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Abstract*—The electromagnetic spectrum plays a fundamental role for the development of the digital society. It enables wireless communications (either between humans or machines) and sensing (for example for Earth exploration, radio astronomy, imaging, and radars, among others). While each of these uses benefits from a larger bandwidth, the spectrum is a finite resource. This introduces competing interests among the different stakeholders of the spectrum, which have led generally to rigid policies and spectrum allocations. Recently, the spectrum crunch in the sub-6 GHz bands has prompted communication technologies to move to higher carrier frequencies, where future 6G wireless networks can exploit theoretically very large bandwidths. The spectrum above 100 GHz also features a much higher density of passive allocations than lower spectrum because of the presence of many molecular resonances in this region. These allocations provide for both environmental sensing satellites and radio astronomy. These passive allocations limit the use large contiguous bands to active users of the spectrum, either being communications (which need tens of gigahertz of bandwidth to target terabit-per-second links) or radars. This abstract introduces two papers [1], [2] that explore the coexistence issues in the spectrum above 100 GHz, and aims at facilitating a discussion on burden sharing and pathways toward studies and policy developments for spectrum sharing and coexistence in these bands.

***Index Terms*—Terahertz Communication; Sub-millimeter-waves; Spectrum Sharing; Passive users; Coexistence; 6G**

I. Introduction

As discussed in [1], the wireless spectrum is a key enabler for a diverse set of applications, from high-speed communications [3], to imaging [4], remote sensing [5], Earth and space exploration [6], and radio astronomy [7]. The finite nature of this resource, however, translates into limited availability of bandwidth for each use case, unless sharing approaches can be found. Thus, new regions of the spectrum and sharing mechanisms have become increasingly of interest over the years.

The spectrum above 100 GHz has recently entered the spotlight as enabler for ultra-high data rate communications [8] and of more advanced sensing solutions [9], as also illustrated in Figure 1. This spectrum region includes large chunks of currently unused bandwidth that could enable broadband communications and new sensing applications.

As a consequence, *both sensing and communications communities have a stake in the spectrum above 100 GHz*, either because of the availability of large chunks of untapped bandwidth, or because of specific frequencies of interest. The different communities, however, often express different needs with respect to how the spectrum should be used. For example, even modest levels of Radio Frequency Interference (RFI) can strongly affect the performance of most classes of passive sensing systems [10], while communications or other sensing techniques (e.g., some radars) need active transmissions. This has led national and international spectrum regulation entities to define a rigid allocation scheme in the spectrum above 100 GHz, with a set of narrow, yet numerous sub-bands exclusively dedicated to passive sensing (i.e., for science and space exploration) [11]. While the total bandwidth reserved for passive users is rather small (i.e., 33.35 GHz between 100 and 275 GHz), the positioning of these sub-bands in the overall spectrum prevents the allocation of large chunks of contiguous bandwidth for active usage. This is highlighted in Figure 2: the largest contiguous chunk allocated to Fixed and Mobile services between 100 and 275 GHz has a bandwidth of 23 GHz, the maximum contiguous spectrum below 200 GHz for Fixed and Mobile communications is only 12.25 GHz (non contiguous). For communications, this is less than the bandwidth that is typically needed to achieve the 1 Tbps target rate of future 6G networks. Similarly, the needs of the sensing community have evolved since when the current regulatory approach was established. For example, the bandwidth that passive sensing systems can capture and process has increased, and new systems can observe molecular features with increase precision and also outside of the ITU protected bands.

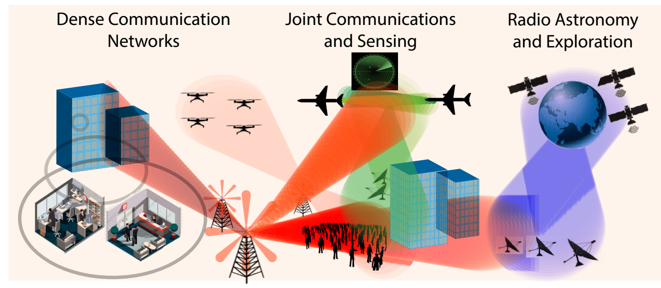


Figure 1: Stakeholders in the above 100 GHz band. From [1].

The research, technology, and policy development in the sub-6 GHz and lower mmWave spectrum has shown how spectrum sharing mechanisms can be effective in providing

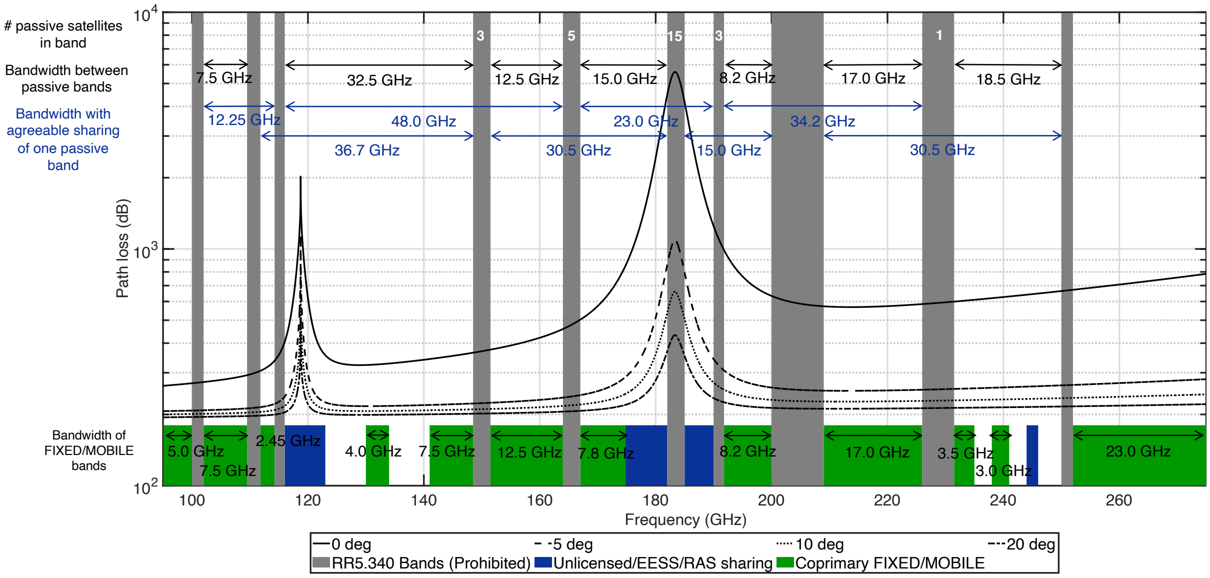


Figure 2: Spectrum allocation above 100 GHz and the path loss for a 407 km Earth-space link with different elevation angles. The figure also highlights existing services, including the number of passive satellites in each band dedicated to passive sensing, and the chunks of bandwidth that are available between passive bands (black) or by enabling sharing of one passive band (blue). From [1].

more spectrum for different stakeholders (e.g., the Citizen Broadband Radio Service (CBRS) example in the 3.55 GHz to 3.7 GHz band) [12], [13]. When considering the spectrum above 100 GHz, the characteristics of devices and propagation in the above 100 GHz introduce new potential and challenges with respect to spectrum sharing approaches in the sub-6 GHz band [3]. The higher absorption and spreading loss above 100 GHz [8], together with directional transceiver architectures [14], allow for increased spatial reuse and coexistence. Similarly, a larger bandwidth can shorten the observation time for sensing and the transmission time for communications, thus potentially enabling more refined and flexible time sharing strategies. At the same time, however, the device and RF circuits design is made more challenging by the high carrier frequency and large bandwidth processing requirement. This makes precise transmit and receive frequency masks more difficult to design, leading to out-of-band emission issues.

The study and implementation of spectrum sharing techniques for active and passive coexistence in the spectrum above 100 GHz is thus a delicate issue, which requires a concerted effort involving the different stakeholders of the spectrum above 100 GHz, and innovations in both spectrum policy and engineering. This abstract introduces two papers [1], [2] that combine expertise from the communications and Radio Frequency (RF) sensing communities to identify possible solutions and developments for a safe coexistence of different services above 100 GHz, and discusses how spectrum regulations and technologies can evolve to accommodate more shared spectrum and use cases that require either larger bandwidths or more agile protections.

In the following, we briefly discuss the contribution of each paper (Sections II and III), and expand on a policy and technology discussion around burden sharing in developing spectrum sharing solutions (Section IV).

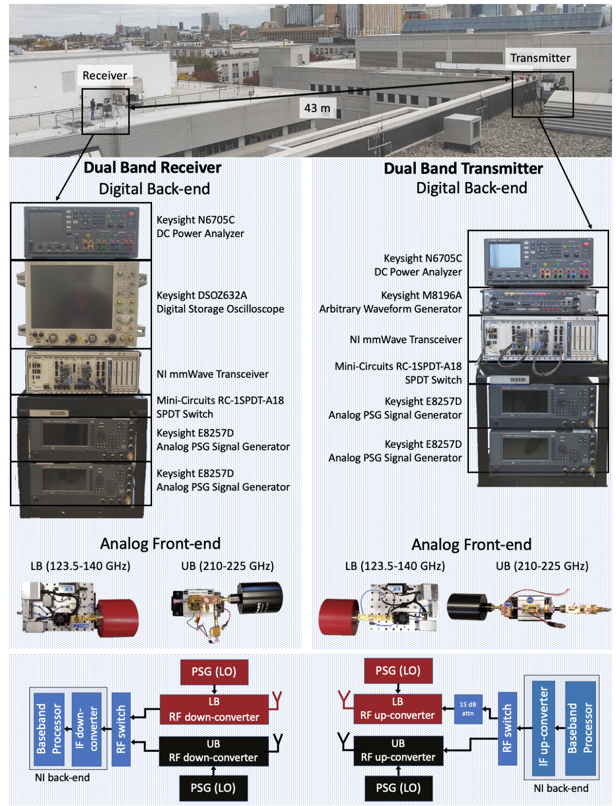
II. Understanding Stakeholders, Policy, Interference, and Spectrum Sharing Solutions Above 100 GHz

The paper [1] provides policy and technological guidance on how sharing can be effectively implemented for the benefit of all the stakeholders in the spectrum above 100 GHz, enabling the digital revolution of the next decade. First, we describe the needs of the stakeholders in these frequency bands, detailing—with numerical examples—why both sensing and communications can benefit from access to large, contiguous chunks of bandwidth in this portion of the spectrum. Then, we describe the current spectrum regulations, highlighting possible policy roadblocks that prevent dynamic spectrum sharing between different stakeholders. In the third paper of the paper, we adopt a physics-based approach to model the interference between active systems and passive users, to understand which scenarios and operating regimes are subject to RFI in the spectrum above 100 GHz. The modeling considers realistic settings and conditions, i.e., high-sensitivity receivers for the sensing systems, and directional antenna arrays in the communication systems, and will be based on International Telecommunications Union (ITU) channel models and antenna patterns. Our analysis highlights that while the high path loss and directional antennas can help reduce RFI in some scenarios, there are configurations (e.g., for high satellite elevation angles) where RFI from terrestrial communications links exceeds the harmful RFI thresholds for passive services set by the ITU.

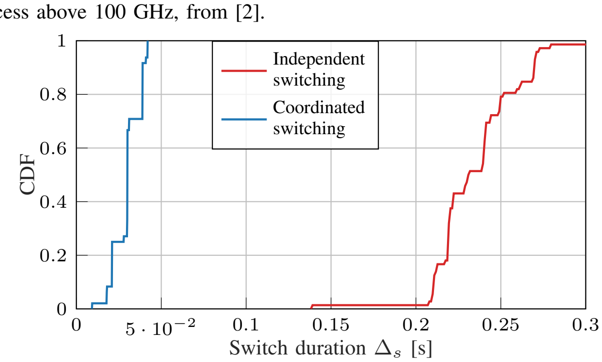
Based on these considerations, we analyze technological enablers of spectrum sharing in the spectrum above 100 GHz, considering full-stack solutions, i.e., hardware-based RFI mitigation (innovative antenna design, antenna arrays, Frequency Selective Surfaces (FSSs)), signal processing for RFI mitigation, and communications and networking design. Finally, we discuss how spectrum regulations and technologies can evolve to accommodate more shared spectrum, proposing a future directions for technology and policy development, experimentation, and commercialization of sensing and communications solutions above 100 GHz.

III. An Experimental Demonstration of Dynamic Spectrum Sharing Above 100 GHz

In the second paper [2], we demonstrate the feasibility of passive/active spectrum sharing through dynamic spectrum access, with the communications stack dynamically adapting to the presence of passive sensing satellites over the deployment area. The system (shown in Figure 3a) is capable of tracking satellite mobility (e.g., the NASA Aura satellite [6]) and predict when a passive-sensing station starts orbiting over the deployment area of the communication link. When this happens, the systems switches from the band that may interfere with the satellite to another band, enabling time-sharing of resources that would otherwise be unused, while introducing no harmful interference to the sensing system. This process happens with a granularity of minutes, i.e., it does not need a tight integration between the sensing and communications stacks. Nonetheless, it is important to perform the switch between bands in a timely fashion, so as to avoid downtime for the communication link. Figure 3b compares the CDFs of the duration of switch events with a coordinated (or centralized) approach and an independent (or distributed) strategy. Even though this is a prototype, the system achieves low switching times (i.e., in the order of ms), especially with the centralized switching, showing that dynamic spectrum access is feasible even in the spectrum above 100 GHz.



(a) Prototype schematics of a dual-band prototype for dynamic spectrum access above 100 GHz, from [2].



(b) Cumulative Distribution Function (CDF) of the duration of a procedure to switch between bands, with a centralized (ccordinated) or distributed (independent) approach, from [2].

Figure 3: Prototype and performance of the first dynamic spectrum access system above 100 GHz, from [2].

IV. Policy Strategies for Spectrum Sharing Solutions Above 100 GHz

The following is an extract from [1] where we discuss policy options to enable studies and development of spectrum sharing solutions above 100 GHz.

At WRC-2000, the US and European Conference of Postal and Telecommunications Administrations (CEPT) proposals also included a provision to study whether sharing of the allocated passive bands with active services was possible without harmful interference [15]. In 2000, on the eve of the commercial introduction of 3G / Universal Mobile Telecommunications System (UMTS) cellular technology, such studies were complicated by the fact that there were few indications of what meaningful telecommunications applications above 100 GHz would exist, or even what data rates would be required in the long term, for either mobile links or the backhaul. Resolution 731 [16] was approved as a compromise between the suggested language of the US and CEPT on spectrum sharing. It states that ITU-R should study possible sharing of the passive bands above 71 GHz with other spectrum uses, and that such sharing must not expose the passive service to interference levels greater than those specified by ITU-R recommendations [17]–[19]. At WRC-19, Resolution 731 was then updated to add new provisions for above 275 GHz, but its provisions within the 71-275 GHz spectrum remained the same, except for updating references to other ITU-R documents.

Resolution 731 specifies explicit interference criteria for Earth-Exploration Satellite Service (EESS) [17] and for RAS [18], [19]. In the case of EESS, the criteria given is a triplet of numbers for each protected band which specifies (i) the reference bandwidth over which interference power should be measured; (ii) the maximum permitted interference level; and (iii) the percentage of the Earth's surface area or time in which the permissible interference level may be exceeded. These power levels are defined at the terminals of the receiving antenna in the satellite. They represent the total power received from the area of the Earth that is viewed by the antenna's footprint, including its sidelobes. A separate ITU-R document [20] gives typical satellite parameters, such as orbit height and antenna characteristics but does not presently cover every possible band (although an update is in progress [21]). The analysis of the available literature on EESS, however, does not exhaustively clarify if all passive satellites have interference vulnerability comparable to that specified in this document. It is also not clear whether there is public information available on all passive satellites entitled to interference protection and their parameters, including orbit parameters.

Finally, Resolution 731 also contains the following provision: "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" [16]. This implies that, when developing sharing strategies, both the active and passive users have an obligation to cooperate to increase the overall use of the spectrum, while also achieving the user-specific objectives. Nonetheless, passive satellite systems do not have the same level of flexibility as active users. The design of satellites and scientific equipment is a multi-year effort, and careful planning needs to be factored in the engineering of the RF components. Once in orbit, there is little or no possibility to change operating parameters and adjust transceiver systems to react to new or unforeseen interfering signals. As of today, most passive satellites orbiting are expensive units, with a mission lifetime spanning 5 to 15 years. It is also difficult to change parameters for satellites that are planned but not launched yet, even if consensus on the policy and sharing technologies is reached. So far, there has been no ITU-R discussion on the concept of "burden sharing" as introduced in Resolution 731, even though this holds long term potential for improving spectrum sharing capability.

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