The More We Share, the More We Have: Spectrum Sharing as the New Frontier

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In Richard Feynman's famous essay, There's Plenty of Room at the Bottom [1], he pointed out that innovation in physics had a great frontier to explore at smaller and smaller scales of matter. In communications, the frontier has been defined not by what has been getting smaller, but rather by what has been getting shorter; that is, not measurements of atoms, but rather of wavelengths. In the last century, the slice of the electromagnetic spectrum that went from 100 meters to 10 meters (or in terms of frequency, from 3 MHz to 30 MHz) was often referred to as "Shortwave" radio. Well, that "short" proved not to be short enough. Since then, the utilized wavelengths have continued to get shorter and shorter as the demand for more radio communications capacity has continued to grow. Today, the frontier of exploitation of the radio spectrum is in what is termed centimeter spectrum, that is, wavelengths in the band from 100 to 10 millimeters, and millimeter spectrum, in the band from 10 to 1 millimeter. Shorter than this is still possible, but then we get into the far infrared and our terminology shifts from talking about radio to talking about light.

Now this seems like a lot of spectrum, but amazingly, demand still seems to exceed supply. Demand is increasing as new uses for radio spectrum are invented. Mobile data's appetite for bandwidth is ravenous. The Internet of Things will drive further demand as the number of connected devices will likely exceed the human population by at least an order of magnitude. Supply will not grow as quickly, however, as a naive assessment of all the new spectrum available might suggest. This is for a variety of reasons, some having to do with the physical characteristics of the medium through which the radio waves have to propagate, and some having to do with the nature of the signals themselves. The walls of buildings and the humidity of the air, as well as propagation characteristics of the signals such as dispersion, reflection, and multipath interference, all conspire to make the usable bandwidth less than the potential once thought to be attainable.

To remedy this situation, the regulatory authorities in many countries have first tried a strategy that we can refer to as slicing, dicing, and trading. They have attempted to find unused spectrum and reassign it to new users. They have convinced some users to give up part of their spectrum in exchange for financial concessions. They have engineered swaps between sectors of users to make more contiguous spectrum available in highly desirable bands. An example of this strategy is the regulatory reassignment of some of the spectrum between UHF television channels (usually called TV white spaces) to mobile data users [2]. Even with these sorts of measures, the demand for spectrum continues to outpace the supply, and regulatory changes are often accompanied by extended political battles that pit one set of users against another, often delaying or preventing these solutions from being deployed.

If going to shorter and shorter wavelengths doesn't solve the problem, and various regulatory schemes haven't solved the problem, what is to be done? Into this conundrum comes a concept straight out of the playgrounds of everyone's childhood. How about sharing? If there is less supply of something than there is demand, how about if everyone takes a turn? In essence, this is moving spectrum assignment from the domains of wavelength and space into the domain of time.

It has been known for some time now that much of the radio spectrum is underutilized at any given moment of time even though all of the available spectrum in a given band has been assigned to particular users [3]. The term "dynamic spectrum sharing" refers to technology that allows multiple users to share that spectrum. How would this be done? A variety of techniques have been proposed. These include using databases that assign spectrum to a particular user based on things like time of day and geographic coordinates. Another technique is a listen-before-transmit scheme that uses sensing to determine whether a channel is unoccupied at a given time. Recently, proposals have been made to recognize, using machine learning techniques, who or what is occupying a channel and whether and at what priority a new user should be given access.

However, much of the work has not considered passive users of spectrum, that is, those using spectrum for observational purposes. These users, including astronomers, scientists doing remote sensing, and others, are typically looking for very small signals in the millimeter-wave bands in the midst of noise. For these users, active use of some millimeter-wave bands poses a threat of interference that needs to be mitigated or guarded against in some way. In the U.S., the National Science Foundation has recently announced a program called the "Spectrum Innovation Initiative" [4], which attempts to create a new technology community to probe these issues. This is not to say that the bands at the "bottom" — at the short end of the radio spectrum — won't be useful for communications, but that more spectrum sharing technology development will be needed so that active communications applications can coexist with passive observational applications. Standards will probably need to be written so that both potential user communities, albeit with differing interests, can be served.

In IEEE, several Standards Committees have already been working in the dynamic spectrum space. The IEEE DySPAN Standards Committee has released the 1900.X series of standards. These standards remain under active development with room for new standards of additional scope and for revisions and amendments to the existing standards. They range in subject matter from terms and definitions for dynamic spectrum sharing to interfaces and databases for distributed spectrum sensing. In addition, the IEEE 802 Standards Committee has released the 802.22-19 standard. This standard addresses both Physical Layer (PHY) and Medium Access Control (MAC) layer enhancements for successful utilization of TV White Spaces spectrum for wireless regional area networks. Continuing technical developments in these areas can be expected, and new standardization efforts are necessary and critical for widespread adoption of spectrum sharing technology.

References

[1] R. P. Feynman, "There's Plenty of Room at the Bottom," in *Miniaturization*, H. D. Gilbert (ed.), Reinhold, 1961, pp. 282–296.

[2] S. W. Oh *et al.*, "An Overview and Comparison of TV White Space Regulations Worldwide," *International Conference on Frontiers of Communications, Networks and Applications* (ICFCNA 2014–Malaysia), Kuala Lumpur, 2014, pp. 1–6, doi: 10.1049/cp.2014.1398.

[3] M. Mehdawi *et al.*, "Spectrum Occupancy Measurements and Lessons Learned in the Context of Cognitive Radio," *2015 23rd Telecommunications Forum Telfor* (TELFOR), Belgrade, 2015, pp. 196–199, doi: 10.1109/TELFOR.2015.7377446.

[4] NSF 20-557 Spectrum Innovation Initiative: National Center for Wireless Spectrum Research (SII Center).