APPROACHES TO SPECTRUM SHARING

BY JON M. PEHA

Many complain about a severe "spectrum shortage." Measurements at Carnegie Mellon University and elsewhere have shown that much of the prized spectrum is idle at any given instant and location. The shortage comes from outdated spectrum policies that allow little sharing. Regulators grant licenses that offer exclusive access to spectrum. When licensees are not transmitting, spectrum sits idle. These policies were once appropriate, motivated by 1920s technology. New technology will enable much more spectrum sharing, unleashing innovative new products and services, provided that we adopt appropriate spectrum policies.

Two camps are pushing for extreme reform, one for "property rights" [1] and the other for "spectrum commons" [2]. The resulting debate sometimes generates more passionate rhetoric than logic. Indeed, it is often unclear whether two advocates agree or disagree, because they routinely use different definitions for the most basic terms. Of course, there are more than two options. This article presents concepts underlying the "property" and "commons" debate, clarifies options for spectrum reform, and describes trade-offs.

THE PROPERTY AND COMMONS MODELS

Property rights advocates compare spectrum to beachfront land. Commons advocates compare spectrum to communal grazing land and other shared resources. The metaphors are useful, but sometimes deceptive.

In a market economy, land typically goes to those who value it most and are willing to pay for it. This occurs because land owners can keep their land indefinitely, use it however they wish, and sell, rent, or lease it to others. Property advocates argue that spectrum users should also have these rights. (Unfortunately, people disagree as to whether a spectrum policy with some but not all of these rights fits the definition of "property.")

Spectrum users could have *flexibility*, the right to use spectrum however they wish, or they could be restricted to specific applications (e.g., cellular), or even specific modulation schemes (e.g., the AMPS cellular standard). Flexibility helps by allowing nimble licensees to put spectrum to its most valuable use with the most effective technology, without waiting for a regulator's permission. However, flexibility prevents regulators from imposing standards, which is a greater problem with spectrum than land [3]. For example, TV stations throughout the United States were forced to broadcast in the same frequency range with the same technology. Consequently, televisions work throughout the country. With complete flexibility, different regions might produce incompatible standards in noncontiguous frequency bands, to the detriment of all.

Another possible aspect of property rights is duration. U.S. spectrum licenses expire after 10 years (although licenses are usually renewed). Should rights be permanent? Temporary rights give regulators a chance to intervene every decade. For example, a regulator may increase the value of spectrum by consolidating underutilized regional spectrum blocks into one nationwide block, possibly compensating displaced licensees. The danger is that uncertainty about future regulatory action may discourage investment [3]. (If spectrum users do not have complete flexibility, rights must be temporary, so regulations can evolve with technology.)

Property rights might allow "owners" to sell use of their spectrum. Just last year, the FCC made *secondary markets* for spectrum legal, so a licensee can now lease rights to use spectrum for the duration of a license [4].

Independent of license duration and flexibility, clear spectrum boundaries are needed. With land, crossing a specified line in the sand is trespassing. However, if one divides spectrum by frequency range and geographic boundaries, some degree of cochannel and adjacent channel "trespassing" is unavoidable, so the land metaphor fails. Since we must allow devices from adjacent frequency bands to cause slight interference in this band, can we allow devices in the same band to cause slight interference? This controversial sharing arrangement is called an *underlay*. Some advocates believe underlays are incompatible with spectrum rights, but in fact it depends on how boundaries are defined. Similar boundary disputes arise over frequency ranges (guard bands) and geographic regions (white spaces) that were intentionally left idle to protect licensees.

In contrast to a property model, the commons model requires spectrum sharing. In a shared band, devices might *cooperate* or merely *coexist*. While both possibilities are sometimes lumped together under the ambiguous heading of "commons," the two are entirely different. The coexistence model exists today, and has spawned successful products such as WiFi and cordless phones. Some argue that making more spectrum of this type available would encourage more innovation. When systems merely coexist, explicit communications is pointless; a cordless phone and a WiFi card do not decode each other's transmissions, although one could sense when the other is transmitting. One may even delay transmission to avoid collision in accordance with rules imposed by the regulator. These rules, known as etiquette, can greatly improve efficiency *if and only if* designed appropriately for the applications in the band [3, 5].

With cooperative sharing, devices communicate with a common protocol and work together [2]. For example, all devices could self-organize to form one ad hoc mesh network. This requires some altruism, where devices sacrifice their own performance or battery power to forward the packet of a stranger. Security is also more problematic in cooperative networks. Nevertheless, if some technical challenges can be overcome and the protocol can be imposed on all devices in the band, the resulting cooperative network could be quite efficient.

With either coexistence or cooperation, a "spectrum commons" could be created by either a regulator or a licensee. The regulator would create an *unlicensed* band. Any device can be deployed in an unlicensed band without explicit permission, provided that the device operates in accordance with the rules. Alternatively, a private entity might obtain a license, establish its own operating rules, and allow devices to operate in its spectrum. The latter approach is particularly appropriate for a cooperative system, because a regulator could have great difficulty imposing a cooperative protocol on diverse devices, whereas an equipment manufacturer with a spectrum license could easily control the protocol used by its devices. (Unfortunately, people disagree as to whether a system fits the definition of "commons" when access is controlled by a licensee rather than a regulator, just as they disagree as to whether the definition

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implies coexistence, cooperation, or either possibility.)

A TAXONOMY FOR SPECTRUM SHARING

Below is a new taxonomy of policies under consideration based on spectrum sharing, ignoring orthogonal issues such as permanence and flexibility. We first consider *primary* users of spectrum and then *secondary* users, where secondary users defer to primary users. Regulatory options for primary and secondary devices are summarized in Tables 1 and 2, respectively.

Systems that require quality of service (QoS) guarantees should be given some degree of exclusivity, as is possible in traditional licensing. If QoS guarantees are unnecessary, primary systems can share a band by either coexisting or cooperating with peers.

Today, regulators control access to spectrum by granting licenses or establishing rules in an unlicensed band. Alternatively, the regulator could grant a license to a private entity that would act as a *band manager*, playing the role of a regulator. The band manager may limit where devices are deployed to guarantee QoS or accept an unlimited number of devices. Band managers would presumably charge for access. There is a danger that a band manager could gain more profit by impeding access than by improving it. To prevent this, regulators might create multiple competing band managers, or impose safeguards against anticompetitive behavior such as a requirement to serve all parties on a nondiscriminatory basis [5].

A secondary user might be allowed to share spectrum, provided that the secondary user defers whenever the primary wants the spectrum. A secondary device might attempt to coexist with the primary, such that the presence of secondary devices goes unnoticed. Secondary devices would then access spectrum *opportunistically*, when they determine that doing so would not adversely affect any primary spectrum users, perhaps using advanced sensors and cognitive radio [6]. Alternatively, a secondary device might cooperate with the primary. Through explicit signaling, the secondary device would learn when it can operate and when to interrupt service. Traditionally, it is the regulator who grants permission for secondary access and defines the signaling protocol. If a primary licensee has sufficient flexibility, it may choose to grant secondary access instead, presumably for a fee. This would be a form of secondary market.

Application requirements	Regulator controls access	Licensee controls access
Guaranteed QoS	Traditional licensing	Band manager makes guarantees
No guarantee, coexist with other primary devices	Unlicensed band; regulator sets etiquette	Band manager sets etiquette; no guarantees
No guarantee, cooperate with other primary devices	Cooperative mesh network; regulator sets protocol	Cooperative mesh network; licensee sets protocol

Table 1. *Policy options for primary spectrum users.*

Application requirements	Regulator controls access	Primary licensee controls access (secondary market)
Guaranteed QoS	Not possible	Licensee guarantees QoS (static or dynamic)
No guarantee, coexist with primary	Unlicensed underlay with opportunistic access	Secondary market with opportunistic access
No guarantee, cooperate with primary	Interruptible secondary operation; regulator sets cooperation protocol	Interruptible secondary operation; licensee sets cooperation protocol

Table 2. *Policy options for secondary spectrum users.*

A secondary system can only have guaranteed QoS if the primary users promise not to interfere, presumably for a fee. Licensees could grant static access to unused spectrum for months or years, much as regulators do today, or grant dynamic access to momentarily idle spectrum for seconds or minutes [7]. In the latter case, secondary devices would make requests as needed. If the request is denied, they might switch to another band.

CONCLUSIONS

Technical innovation will lead to spectrum reform. Advocates are pushing for "commons" and "property" models, but there is a diverse set of models to consider, each with its own advantages. Different models can be adopted in different bands. Models should be selected based on practical implementation considerations. Above all, we must consider the applications.

Should primary spectrum users be licensed, or should spectrum bands be unlicensed? It depends. Licensing works better for TV broadcasting, with its strict QoS requirements. Unlicensed spectrum works better for wireless connections between computers and cable modems, with their sporadic transmissions and ability to retransmit.

Should secondary devices use spectrum opportunistically, or coordinate through a dynamic secondary market? It depends. Opportunistic access is less challenging technically if transmissions from licensees are predictable, as with broadcasters. Although secondary devices get no QoS guarantees, this is fine for some (but not all) applications. On the other hand, the dynamic secondary market may be more appropriate where licensees are cellular carriers, because a little coordination can allow many secondary devices to transmit while protecting the QoS of both cellular customers and secondary devices [6].

While allowing innovators to use spectrum in unexpected ways, we should establish spectrum policies likely to support growth of the most desired applications — whatever those are.

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