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# SPECTRUM MANAGEMENT POLICY OPTIONS

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## ABSTRACT

As market-based reform sweeps telecommunications industries around the world, it is a good time to reevaluate the spectrum management policies which govern wireless industries ranging from broadcast television to satellite communications. Most countries have been using a central planning approach to spectrum management, but there are many alternatives with varying degrees of flexibility and market-based incentives. This paper provides a survey of spectrum management approaches, addressing methods of determining how spectrum can be used, which commercial entities can use it, and how governments can manage their own spectrum. It identifies some of the crucial choices to be made, and summarizes advantages and disadvantages of each.

Increasing use of wireless devices early in this century led to extensive mutual interference and unpredictable performance. Emerging applications like broadcast radio could never have prospered in this chaos. National and international organizations restored order by controlling usage — creating bureaucracies for central planning — but this is not the only way to address the problems of mutual interference. Indeed, this approach contrasts sharply with today's worldwide trend toward market-based policies in other aspects of telecommunications, as shown by Europe's plan for competition in 1998, the United States Telecommunications Act of 1996, and the introduction of competition in telecommunications sectors throughout the world — from Guatemala to Ghana. A few nations such as New Zealand have led the way in bringing market-based reform to the context of spectrum management, or at least one possible approach to market-based reform. Ultimately, engineers, economists, and regulators in every nation will have to combine their expertise to determine what reform, if any, is appropriate. To aid this reform process, this article surveys various policy options.

We address three critical issues of spectrum management in the next three sections: regulating how spectrum can be used, determining which commercial entities can use spectrum and any associated fees, and providing spectrum for government use. For each of these issues, we will describe various policy options, and summarize the crucial advantages and disadvantages of each. The final section provides a brief summary and discussion of the issues and tradeoffs.

## REGULATING HOW SPECTRUM IS USED

The following sections address three aspects of how spectrum may be used: the extent to which it is shared, the role that government plays in determining the application and technology, and whether this role is established temporarily or permanently. In each case, policy alternatives and their pros and cons will be presented. The possibility of combining these various alternatives are then discussed.

### EXTENT OF SHARING

In the simplest approach, government divides spectrum into non-overlapping blocks. Licenses are then distributed, where a license gives its recipient the exclusive right to transmit in one such block of spectrum in a given geographic region. Clearly, exclusive access solves the problem of mutual interference with no need for coordination (although there can be opportunities for some negotiations along spectral and geographic boundaries, where guard bands are generally needed). Consequently, most spectrum throughout the world is licensed in this manner.[1]

In stark contrast is unlicensed spectrum, in which no licenses are granted, and any device is allowed to transmit [1-7]. Restrictions are imposed on the access protocols to allow devices to coexist. (Examples in the United States include the Industry, Science and Medicine Band, and more recently, a portion of the Personal Communications Services band and the National Information Infrastructure band.) This approach has several advantages, including its ability to support many mobile devices that are ill-suited for licensed spectrum. Consider an attachment to laptop computers that would allow two or more laptops to form their own portable wireless local area network (LAN), or a portable wireless private branch exchange (PBX) phone system that is moved from one construction site to another. With unlicensed spectrum, a user need not obtain permission to transmit from any location where she might ever want to be. Another important advantage of unlicensed spectrum is that it allows spectrum-sharing. For example, with traditional licensed spectrum, spectrum sits idle at times when the license holder is not transmitting, which is clearly inefficient. With unlicensed spectrum, many devices can share the same spectrum, so that when one is not transmitting, another can. Such sharing greatly increases the

[1] *In some bands, there is also some limited sharing in the form of "primary" licenses and "secondary" licenses, where secondary license holders can use the same spectrum provided they do not interfere with primary license holders.*

potential for spectral efficiency, i.e., more traffic can be carried when spectrum is shared [4, 8, 9 ].Unlicensed bands also eliminate the potentially lengthy and expensive process of distributing licenses, thereby promoting experimentation and innovation. It has even been proposed that all spectrum should be unlicensed [10], based on the premise that technical innovation has eliminated spectrum scarcity. Alas, while technical advances have indeed increased the amount of useful spectrum, demand is also increasing rapidly, and it seems unlikely that spectrum scarcity could end any time soon.

As long as that scarcity remains, unlicensed spectrum has some serious problems. First, the rules of coexistence may somewhat limit the kind of technology that can be deployed. Second, with no limit on the number of devices sharing the spectrum in a given location, there can be no guarantee that performance will be adequate. Third, although spectrum sharing tends to improve spectral efficiency (i.e., the amount of data transmitted over a given spectrum block), sharing does not necessarily improve economic efficiency (i.e., the total value of all data transmitted over a given block of spectrum). Spectrum that is freely available may be used for applications of negligible value. Finally, any time a resource is shared by many users, no single user has strong incentive to conserve the resource [1–4, 8, 9]. For example, a device that wants to ensure that spectrum is available when desired may simply transmit all the time [1–3]. This prevents other devices from holding the spectrum when this device may want to transmit, and it is also extremely wasteful.

Early research indicates that these disadvantages can be addressed in part by carefully designing the rules of coexistence in unlicensed spectrum [1–3]. These rules can make a given unlicensed band more useful for targeted applications than other types of applications, and more importantly, can create disincentives for squandering spectrum [3]. For example, a device that has been transmitting for long periods at high power may subsequently be given a reduced chance of gaining timely access to the spectrum when contending with other devices. Itis likely that any approach that discourages greed will be incompatible with some applications, such as broadcast radio and television, which need to transmit continuously. Indeed, different rules of coexistence will be more conducive to different applications, so there is no single set or rules that is optimal.

As a final alternative, one might try to offer a system with open access similar to unlicensed spectrum within a licensed framework. A license holder would allow many devices to use its spectrum without a prior licensing agreement in return for some compensation. The ideal approach would be for the wireless device to negotiate a price with the wireless infrastructure for each transmission [11]. This is appealing because, as with Internet pricing, an appropriate price would give every device an incentive to conserve the shared resource [12]. However, massive infrastructure would be needed so that mobile devices can communicate with the license holder to request the right to transmit, and to agree on a price. Methods would also be needed for authentication, transferring payment, and monitoring actual usage to make sure that all transmissions are paid for. Thus, transaction costs are likely to be too high with this approach. A less effective but more practical method of providing licensed open access is for a device manufacturer to compensate the license holder for every new device created and sold. For example, for every device operating at a given frequency that Nokia builds and sells in Canada, it would pay a fee to the holder of the Canadian license at that frequency. The problem of incentive to conserve spectrum returns; although, perhaps if there are few manufacturers and they are willing to reveal a great deal about the access protocols in their products, then this problem can be dealt with through direct negotiation [4]. Enforcement is also particularly problematic with this approach. How would the Canadian license holder know if devices used this band without paying? The other weakness of this approach is that the license holder has little incentive to protect the interests of devices that have already been deployed, since they generate no new revenue.

## EXTENT OF FLEXIBILITY

For each block of spectrum, government can determine which application will be selected (e.g. television or cellular telephony), and it can determine the transmission standard. Under the traditional central-planning approach, governments have generally done both.

An alternative is the flexible use doctrine, whose supporters include Reed Hundt, the former head of the United States Federal Communications Commission (FCC) [13]. The goal is to allow market forces to influence decisions wherever it is possible within a licensed spectrum management framework. License holders are free to choose what they will use their spectrum for, provided that interference levels for adjacent frequency blocks and neighboring geographical regions do not exceed set thresholds. Thus, if AM radio becomes less profitable, AM stations can offer paging services instead. They can also sell secondary rights so that other firms can use the spectrum in ways that do not interfere with AM radio broadcasting. License holders can also choose any technical standard they wish. Finally, license holders in adjacent bands can negotiate the extent to which they interfere with each other, rather than accepting the interference levels set by the government. Thus, if one service can tolerate additional interference, a neighbor can make use of this for some financial compensation, thereby improving spectral efficiency. This is particularly useful because designers cannot always accurately predict what interference levels will be when a system is deployed.

There are many advantages to a policy that allows individual firms rather than the government to decide how to use each block of spectrum. Spectrum is then used to provide the most valuable services, with the most cost-effective technology. Regulators cannot accurately predict which service and technology will prove to be the most valuable. Moreover, needs vary: rural and urban areas sometimes prefer different wireless services, and this can only be accommodated if some spectrum is flexible. With this flexibility, innovation is encouraged, since firms need not wait for approval to offer a new service. Competition is enhanced, since the government no longer determines how many licenses (i.e., competing firms) to create for a given service; this is determined by the market [8, 9]. Thus, there is strong motivation to allow such flexibility.

There are also three critical advantages to a more activist government role in determining which application will be offered in a given frequency range, and possibly which transmission standard will be employed. One is that the government may then represent industry in negotiations with other nations who may use a similar system. (Electromagnetic waves have an annoying habit of ignoring national boundaries.) A second advantage is that government may ensure that certain applications receive an adequate amount of spectrum. There are applications with positive economic externalities, i.e., that bestow benefits on people who do not have to pay the costs. If license holders are free to select the application that has the greatest return on investment, they will tend to under-invest in these applications. Examples might include amateur radio transmissions in areas where such capabilities are important in case of fire or earthquake, and "free'' broadcast television

| | |
|---|---|
| Open access | Unlicensed open access (restrictions on access protocols)<br>Licensed open access (individual spectrum users pay license holder) |
| Exclusive access | Permanent licenses, flexible use (property model)<br>Temporary licenses, flexible use<br>Temporary licenses, application restrictions<br>Temporary licenses, application and transmission standard restrictions |

**Table 1.** *Summary of policy options governing use of a given block of spectrum.*

(i.e., television supported by advertising or charitable contributions rather than by subscribing viewers).

The most subtle benefit, but perhaps the most important, is standardization. Thanks in part to spectrum management policies based on central planning, a traveler driving across most countries can listen to the same AM radio and make calls on the same cellular phone virtually anywhere, and manufacturers can produce these items for a large mass market. This is possible because all regions have allocated the same range of frequencies for cellular telephony and AM radio, and because license holders transmit using the same transmission standards. Otherwise, customers would purchase equipment that is useful only in select regions, or would have to purchase expensive multimode equipment that essentially includes multiple receivers: one for each frequency range and transmission standard. Of course customers and service providers benefit when a nationwide standard is reached, so there is some incentive for players in a market-oriented flexible system to do so, but is that incentive sufficient? Sometimes, but not always. For example, there is incentive for the computer industry to settle on a single operating system for personal computers, but after many generations of computers and heroic (and sometimes allegedly illegal) efforts by Microsoft, there are still multiple operating systems. Moreover, even when a free market does reach consensus on a single standard, it is not always the best standard. For example, the VHS standard beat Beta in the video-recording market because two-hour VHS tapes were available a few crucial months earlier, not because the technology was better. (In the language of economics, the inherent externalities concerning standards sometimes lead to market failure.)

The emergence of a single standard largely depends on the cost of standardization, and on the industry structure. The former is more obvious. If the cost is great for a firm to abandon its current technology and adopt something closer to what other firms are offering, the firm is less likely to do so. For example, there may already be a large installed base of expensive equipment that the firm and its customers would not want to replace. Consider the heated debate about whether Americans should give up their analog television sets for a potentially superior digital alternative [14]. Could television-owners be prepared to consider incurring this expense to harmonize to a standard of equivalent quality?

As for industry structure, whether a single standard emerges depends in large part on the extent to which an equipment buyer may need to communicate with "unrelated buyers'' [15]. For example, if fax machines are used only to communicate within a company (i.e., among related buyers), then different companies can use different standards. However, if fax machines are used to interconnect unrelated individuals throughout the country, then a single standard is likely to emerge. Consider the case of AM radio in a single city. Stations want to reach all listeners, and residents want the ability to receive all stations. All are unrelated equipment buyers with a need to communicate, so there is strong incentive for all stations and residents of this town to reach agreement on a single standard. However, the incentive to reach such an agreement with stations 2000 miles away is much smaller, since few residents will travel that distance with their radios. The benefits may not outweigh the significant costs of negotiating a standard. With this industry structure, different standards are likely to emerge in different regions. The situation may be even worse with communications services like cellular and paging in which customers are served by a single carrier. A carrier creates a de facto standard, and there is little incentive to coordinate with other carriers.

If the government wishes to facilitate interoperability across regional boundaries, it must encourage license holders offering the same service in different regions to do so at the same frequency with the same transmission standard. The former is probably more important than the latter. Consider a company that is launching a new cellular system in a regulatory environment where the doctrine of flexible use prevails. The company will seek the cheapest available spectrum in the region where the firm plans to operate. The fact that the same frequency is used for cellular in other regions may be seen as an asset, or it may be seen as a liability, since it limits the firm's potential for expansion. It is therefore quite unlikely that a block of spectrum would emerge nationwide for cellular unless it was created by a single company. Those companies that succeed locally may later wish they could build a nationwide coalition to allow roaming, but it could be too late to move to new frequencies. It is already expensive for cellular companies to change transmission standards from analog to digital, but this cost is small compared to the cost of acquiring new spectrum at a different frequency and replacing all frequency-dependent equipment owned by either the cellular provider or its customers.

As for transmission standards, there are a range of options. For example, government can select and require a specific standard, it can require a standard initially and then allow the market to decide thereafter, or it can require a minimal amount of interoperability and allow flexibility beyond that, as in the U.S. policy on digital television. The best choice depends on the nature of the service and the extent to which there is consensus among manufacturers, service providers, and consumers.

Eventually, inexpensive receivers may emerge that can easily switch from one frequency band to another and one transmission standard to another. If these features can be added at negligible cost, it would greatly reduce the incentive for a significant government management role. There have already been great advances in building broadband receivers with tremendous dynamic range, and in implementing control functions in software [16].However, sufficiently inexpensive devices of this kind are still well beyond our grasp, and any reform of today's spectrum management policies cannot depend on this technological progress.

## Temporary Rights Versus Permanent Rights

If spectrum users are granted exclusive access, that access could be temporary or permanent. Throughout the world, nations have long been using a system of temporary spectrum licenses. When the license expires, the license holder applies for renewal. This gives the government a chance to deny renewal and give the license to someone else, or at least to change the transmission standard or other rules governing that spectrum block. Thus, the fact that licenses expire gives the government significantly more control in managing spectrum resources.

In practice, this renewal process is sometimes more ritual than reality. For example, from 1982 to 1989, 99.9 percent of

| | |
|---|---|
| Comparative hearings | |
| Lotteries | |
| Auctions | One-time payments versus annual usage fees<br>Auctioning initial release of spectrum only vs. auctioning renewals as well |

**Table 2.** *Summary of policy options for dispensing licenses.*

all spectrum licenses in the United States were renewed successfully [11]. This is a hint that the government could be removed from this process entirely. Indeed, New Zealand has already made a strong move in this direction [17], and an even more extreme approach has been proposed in the U.S. Senate [17]. Instead of viewing spectrum as something unique, spectrum would be treated like any other property. License holders would own their spectrum indefinitely until they chose to sell or trade it. This would eliminate the licensing bureaucracy. Moreover, as with any limited resource that is allocated through a free market, spectrum would go to those who value it the most, and are therefore likely to use it to maximum advantage. The penalty is the loss of a useful government management role. While governments routinely enforce minor zoning restrictions on land owners, they cannot make fundamental changes in how property can be used without undermining the advantages of a free market. If spectrum is permanent property, a government can hardly tell a television broadcaster that it must tear down its towers and use its spectrum for cellular telephony instead. Thus, instead of a government role in setting standards, the flexible use doctrine should accompany permanent property rights to spectrum. Similarly, it would be inappropriate to create a new nationwide unlicensed spectrum band if it means reclaiming private property, which would require extraordinary use of eminent domain powers, so opportunities for open access would be limited.

### A Multifaceted Approach

Table 1 summarizes the options discussed in this section. Government can grant spectrum property rights, temporary licenses allowing usage flexibility, temporary licenses with restrictions, or government can make spectrum unlicensed. Each has its pros and cons, which is motivation to employ a multifaceted approach. For example, if unlicensed spectrum is better suited to support wireless local-area networks for laptop computers, and licensed spectrum is better suited to support broadcast television, then one might create some licensed bands and some unlicensed bands. Moreover, recall that the advantages of flexible use include industry's ability to offer the most valuable wireless service without government action, and to meet the diverse needs of different communities. These benefits can largely be obtained if some spectrum is flexible, while nationwide standards are encouraged or even enforced in some other bands.

## Determining Who Gets Spectrum

In this section we first describe the three most prominent methods of determining who will get the license for a block of spectrum when it is first released: hearings, lotteries, and auctions. Since auctions are gaining in popularity, we then focus on a unique problem of auctions. Finally, we address the possibility of auctioning license renewals rather than just newly released spectrum. Policy options are summarized in Table 2.

### Distributing New Licenses

Comparative hearings fit well in a central planning approach to resource management. Government gives licenses to those it believes will best serve the public interest, even when there isn't a strong profit motive to do so. Consequently, comparative hearings give an omniscient and impartial regulator the power to distribute licenses optimally. Unfortunately, omniscient regulators are hard to find. If two contenders for a license plan to offer different services, it is sometimes difficult for a regulator to determine which would better serve the public interest. This is one reason why the hearing process can be slow, and delaying the release of spectrum for a valuable service can be costly. In a notorious example of such costs, it has been estimated [19] that regulatory delays in launching cellular service siphoned more than US $86 billion from the U.S. economy.

It is possible to reduce delays by using lotteries instead of hearings. This also ensures that the process will be devoid of political favoritism, which is a serious danger with hearings. Of course, random selection makes it impossible to give preference to those who would take maximum advantage of the spectrum. Moreover, the process encourages frivolous and wasteful applications. If the auction winner is not allowed to sell the license, then the spectrum may go to a relatively unimportant use. If licenses can be sold, then after the lottery, they will be sold to the highest bidder.

It is a short step from private spectrum auctions to public spectrum auctions. Licenses are given to the highest bidder, and the money goes to government coffers. Such auctions have recently been used in the personal communications services (PCS) band in the United States [20], and in a number of other countries including New Zealand [17], Mexico, Chile, and Guatemala. Auctions have two important advantages. First, since licenses go to those who value them the most, spectrum is likely to be used for the most valuable application. Consequently, many economists have been advocating spectrum auctions since the 1950s [21-25]. Second, auctions generate wealth that can be used to pay for other government programs. Unfortunately, the latter strength is also a significant weakness when compared with hearings and lotteries, as is discussed next.

### Dangers of Using Auctions to Generate Revenues

Auctions may be victims of their own success. Revenue generation is a useful side effect of spectrum auctions. However, maximizing revenues is not always in the national interest. This inappropriate exploitation of spectrum auctions may take several different forms.

One danger comes from the fact that auction participants are trying to maximize their profits rather than serve the public good. It is hoped that in a free market these two goals will roughly coincide, but sometimes they completely diverge. One example is if firms can bid on a license that would give the winner a monopoly. This license to overcharge consumers will therefore bring in more money in the auction, but is certainly not in the public interest. The existence of flexible spectrum is some defense against monopolies, but it may not be sufficient. Additional regulations to prevent a single firm from obtaining too much spectrum in a given region are also important. Another way to increase auction revenues to the detriment of the public good is to allow the new license holders to interfere with incumbents in ways that the incumbents could not have anticipated when they obtained their licenses.

Government can also strongly influence auction revenues by controlling when spectrum is released and how much. The

best way to maximize long-term revenues is to inflate the value of licenses by artificially creating scarcity, i.e., not releasing much spectrum. This is especially effective at maximizing revenue with high-frequency licenses where receiver costs are high but falling: more revenue is derived by depriving the nation of use of this spectrum until receivers become inexpensive [26]. Short-sighted lawmakers, which may be more common than those maximizing long-term revenues, are more likely to err in the opposite direction: releasing too much spectrum too quickly. The resulting revenue may be somewhat smaller over the long term, but it will be available soon enough to be counted against today's expenses. This was certainly one driving force to accelerate the switch to digital television in the United States. This switch would make current television spectrum available for auction earlier, but it may or may not be the appropriate timing for television broadcasters, television manufacturers, or consumers. Worse yet, any time short-sighted lawmakers pay for annual expenses through the one-time auction of a national resource, whether its spectrum or land, they may be forced to auction more of that resource every year, whether or not its a good idea.

The best counterweight to this dangerous temptation is to change the way revenues are transferred to the government. Instead of requiring auction winners to make one-time payment to the Treasury, they could pay an annual fee which initially equals their winning bid. Spectrum fees may increase with inflation thereafter. Since these revenues are renewable, they can reasonably be used to support annual expenses. The fact that far less capital is needed initially to acquire a license would also make it easier for small businesses to compete. Note that auction winners must still be required to make a non-refundable payment immediately. This discourages firms from bidding artificially high and using the threat of non-payment (or bankruptcy) to negotiate for lower payments, as occurred in the U.S. PCS auctions. This practice thoroughly undermines the advantages of auctions. The disadvantage of annual fees is that a bureaucracy is needed to collect annual fees.

### Auctioning License Renewals

Typically, once a license is acquired, the license holder does not need to worry about losing that license. This section explores an alternative approach in which license holders must periodically compete in open auctions for their license. In effect, this means spectrum is leased for the duration of a license (which should be reasonably long). A variant of this approach was recently adopted in El Salvador. We will first describe advantages and then disadvantages.

Probably the most important benefit of this approach is that it protects the government's ability to redefine the rules governing a block of spectrum. As mentioned earlier, when government grants long-term rights, and especially if it charges market value for those rights, then it is at least morally if not legally limited in how it can change those rights. It would not be appropriate for the U.S. government to raise money by auctioning Yellowstone National Park to logging and mining operations, and then inform winners after the auction that zoning restrictions preclude them from doing any thing with the land other than making it a park. Moreover, auctions are economically efficient only if all the bidders know what they are bidding on.

There are many reasons why one might want to change the rules governing a block of spectrum. Some have to do with standards issues discussed in the second section, like moving existing license holders out to make room for a new (licensed or unlicensed) nationwide service, or giving existing license holders the opportunity to offer more valuable services through increased flexibility. Changes may also have to do with public service obligations, like requiring cellular providers to offer an emergency service or requiring television broadcasters to provide more educational programs. Such services benefit the community at private expense, which makes it a dangerous practice. Its like requiring private grocery stores to donate food to the poor. The license holder may also want to change the rules. For example, New Zealand now employs auctions for newly released spectrum, and firms have won licenses, and then sent armies of lawyers to request that geographic boundaries be expanded and interference thresholds be improved, thereby increasing the value of their new licenses [17]. Perhaps the technical rationale for all these requests has been well founded, and perhaps not. However, when some firms pursue such strategies, politics returns to the process, and licenses do not always go to those who value them the most. These problems are avoided only if a change in the rights of the license holder leads to an appropriate change in the cost of the license. This occurs if the new rules will apply only after the current license expires and the winner of the next auction takes over. Any redefinition of these rights is announced before the auction.

Another important advantage of periodic auctions rather than one-time auctions is that periodic auctions can be synchronized, allowing bidders to acquire multiple licenses simultaneously in adjacent frequencies or adjacent geographical areas, perhaps even nationwide. Firms are therefore better able to exploit economies of scale, support widescale roaming, and use broadband technologies. This has been demonstrated by the simultaneous auction of many licenses in the United States [20] and in Mexico.

Finally, government can learn a great deal about the true value of spectrum from the winning auction bids. This information is invaluable when spectrum must be used for a specific purpose, as discussed previously. If the bids for a particular license fall every time it is re-auctioned, and the same is not occurring for licenses with flexible use, then it is a signal that the restrictions on that license should be reviewed and possibly changed. The license holder may be deriving less value from the spectrum than is possible. Other uses of this information for management of government spectrum will be discussed in the next section.

There are two disadvantages to auctioning renewals: one is the administrative overhead; the other is that license holders have less long-term security, and may be less inclined to make long-term investments. It would be rare for a firm that has already made capital investments to be outbid by one that has not, but certainly not impossible. This is especially problematic for wireless applications requiring long-term investment in an expensive infrastructure. To reduce the impact when an incumbent is outbid, renewal auctions should be held well before the current license actually expires to minimize the transition cost. In extreme cases, some compensation for the incumbent could be allowed in spectrum blocks where very long-term investments are required. (As always, those rules must be set well in advance.)

## Government-Held Spectrum

Government is typically the largest single user of spectrum. The simplest management approach for government spectrum is, as usual, central planning. Agency heads can come together to describe their spectrum needs, and carve up the government spectrum. This section presents two unusual alternatives, in which the same market-based con-

cepts under consideration for the commercial sector are applied to the public sector.

It is not unusual for government to hold a valuable resource and use it for public service. For example, the government holds valuable land for public parks, prisons, and schools. However, the value of land is well understood, and the amount of land needed to build a school of given capacity is easily determined. The value of spectrum is poorly understood, and the amount of spectrum that should be used to offer a given service changes as technology evolves. Consequently, a government agency is more likely to hold a resource like spectrum without accounting for how valuable it is, and as a result, waste it. For example, an agency may use antiquated equipment to "save money,'' when it could spend a little money to improve the efficiency of its infrastructure and release a large block of extremely valuable spectrum. A solution is to make government agencies pay annual spectrum fees at market value. If forced to pay what the spectrum is worth, the agency is more likely to seek the most efficient solution, possibly by modernizing, seeking wireline alternatives to using spectrum, or even using a commercial service rather than building its own infrastructure.

The question is how to determine the proper usage fee for government agencies. The most effective method of establishing true market value is for government agencies to bid for spectrum in auctions, contending with commercial entities. However, participating in auctions requires nimble management, which is not a strength of most government agencies. The alternative is to calculate usage fees from winning auction bids in other spectrum bands. Under this approach, fees would be farther from true market value, causing some inefficiencies, but fees would be more predictable. The latter approach is particularly important for military and intelligence uses in which security is an issue, because when spectrum is auctioned, much information is revealed about both incumbent spectrum users and bidders.

The government purchasing spectrum rights from itself should require no new net tax-payer money. To make this work, however, auction proceeds must be shared with those agencies that need access to spectrum. In large countries, this may be done hierarchically. For example, within a given range of frequencies, all proceeds from a spectrum license go to the local government where that license applies rather than the federal government. The local government can use this money to acquire its own spectrum, to modernize its equipment, to pay for commercial wireless services, or simply to reduce local taxes. Consequently, spectrum conservation is rewarded. Options for government spectrum use are summarized in Table 3.

| Central planning | |
|---|---|
| Government pays market value for spectrum | By participating in auctions<br>By paying estimated market value based on commercial auctions |

**Table 3.** *Summary of policy options for managing government spectrum.*

## DISCUSSION

Spectrum has traditionally been managed through central planning, where government determines the application and technology for every block of spectrum. With market-based reforms sweeping other parts of the telecommunications industry worldwide, this is a good time to consider alternatives in spectrum management.

One way to replace the central planning approach is to use market-based mechanisms. Options include auctioning licenses for newly released spectrum, auctioning license renewals, and removing all restrictions to license resale. Another approach is to allow spectrum users more power to determine how they use the spectrum. Such approaches include adopting a flexible use policy, replacing temporary licenses with permanent property rights, and making spectrum unlicensed.

As this article demonstrates, there are many tradeoffs implicit in these policy decisions, and nations with different needs and traditions will undoubtedly choose different paths. The remainder of this article abandons the balanced discussion, and describes one inviting path.

Making spectrum unlicensed is the most drastic change. Despite some proposals to the contrary, there is no evidence that the unlicensed approach can completely replace licenses. There are certainly advantages to unlicensed open-access spectrum bands, as well as significant technical problems to be overcome. If (and only if) demonstrable progress is made, many additional bands should be created. There are some significant positive signs [3], but caution is still advisable [1–3].

There is also strong incentive to move toward market-based mechanisms such as auctions in commercial spectrum management, thereby creating incentives for efficiency, encouraging innovation, allowing regional diversity when it is advantageous, and increasing competition. Spectral efficiency would be further improved if government agencies adopted some of these market-based mechanisms, i.e., paying market value for spectrum. Agencies could either participate in auctions directly or pay estimated market value based on bids for commercial spectrum.

However, caution is also in order when introducing market-based reform, because doing so can undermine the government's ability to play a useful management role. The policies recently adopted in the United States for PCS spectrum are illustrious. The newly released spectrum is auctioned, and winners make one-time payments for temporary licenses. They are also given complete usage flexibility. This policy has significant advantages if applied judiciously, but if widely applied, it would undermine the government's ability to manage the spectrum and set standards. If the government's ability to manage spectrum is deemed truly unimportant, it is better to treat spectrum as property by granting permanent licenses, and thereby eliminate a large bureaucracy. Technology may eventually reach the point where this is a good approach. In the meantime, licensing should continue, and the flexible use doctrine should be applied to some, but not all, spectrum. The government's management role is further enhanced in a market-based system if license renewals are also auctioned.

Another danger of free-market mechanisms, especially auctions, is that short-sighted government leaders will try to maximize revenue. The only complete solution is responsible leadership, but it would help to charge auction winners annual fees, even though that leads to a somewhat larger administrative cost. That way governments could not use one-time payments to pay for annual expenditures.

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