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Spectrum Buyouts
A Proposal for the Transition to Open Spectrum

Nobuo Ikeda
Research Institute of Economy, Trade and Industry (RIETI)
Phone: +81-3-3501-8286
E-mail: ikeda-nobuo@rieti.go.jp

Abstract

To remedy the stalemate of spectrum policy, regulatory reforms are being proposed to assign exclusive rights to spectrum. Such reforms are harmful because wireless LANs enable far more efficient communications by sharing a wide band. So it would be better to open the spectrum as *commons*, instead of dividing it into narrow bands. I propose a system of *spectrum buyouts,* by which the government would take back spectrum from incumbents and reopen it for use without a licensing requirement. The prices of these reverse auctions would be much cheaper than that of ordinary spectrum auctions.

1. introduction

In November 2002, the Federal Communications Commission (FCC) published a report written by the Spectrum Policy Task Force (SPTF). Summarizing a half year of extensive research and discussion, the report is indeed impressive in its deep understanding of digital wireless technologies and its call for bold reforms. Particularly noteworthy is the FCC's commitment to depart from the *command and control* approach that regulates usage by licensing. It is also remarkable that the FCC recognized the efficiency of the *commons* approach, which shares a wide band and enables the overlay usage of spectrum by different kinds of terminals.

However, the SPTF's conclusion is a half-hearted compromise between the commons model and the *exclusive rights* model, according to which incumbents can sell and buy their spectrum on secondary markets. SPTF insists that this “market-oriented” approach is more efficient than the commons approach for the band in which “scarcity is relatively high and transaction costs associated with market-based negotiation of access rights are relatively low” (FCC 2002: p.38). They claim that spectrum is scarce below 5 GHz because of its propagation characteristics and “high level of incumbent use.”

Scarcity cannot be the justification for property rights. Roads, parks and streetlights, for example, are all supplied as commons even though they are scarce. In standard economics, a resource is efficiently allocated as private goods if its consumption is *rival* (the marginal cost of consumption is large) and its supply is *excludable* (externality is small). In principle, the externality of resources can be internalized by dividing common resources and assigning property rights to the parts, which can be priced and allocated efficiently by a market mechanism (Coase 1960).

The externality of common resources is often so large that they cannot be excluded without destroying value. Such an example is ordinary road traffic; the road is rival because traffic jams will take place if too many cars are on he road, but it would be inefficient to exclude each car by building fences on the road. It is enough for each car to drive while avoiding other drivers. The exclusive-rights model of spectrum management is similar to such a “fence-on-the-road” approach.

“Transaction (excluding) costs” are not given exogenously, but determined by market structure, regulation, and technologies adopted in the band. Exclusion is needed only in so far as the spectrum is separated by frequency. If terminals are intelligent, they can allocate spectrum dynamically by identifying each other’s signals without exclusion, as we shall see later. In fact, alleged scarcity and transaction costs are *created* by old technologies and poor spectrum management based on exclusive rights. Therefore it would be circular logic to justify exclusive rights by the scarcity that is created by exclusive rights.

2. Open Spectrum

Is Spectrum a Scarce Resource?

The auction was hit upon as a mechanism for allocating spectrum efficiently, but it was based on the dubious assumption that the spectrum is a scarce resource that the government has the right to allocate. “[I]s the spectrum the government’s to sell in the first place?” asks Noam (1998: p. 771), “Could the state sell off the right to the color red? To the frequency high A-flat?” He cited the licensing of spectrum as a violation of the freedom of the press. To understand this problem, it is necessary to distinguish *frequency* from *spectrum*. Frequency is not a resource but a *parameter* used to modulate original data (baseband) into radio waves, so it cannot be scarce any more than amplitude and phase are (Benkler 1999).

In radio communications, transmitters modulate basebands into airwaves by mixing them with carriers of a specific frequency and send the wave in radial form. Receivers identify radio signals by tuning in to the desired frequency and filtering out other frequencies. When basebands are modulated into radio waves, they are distinguished by the frequencies of their carriers. Sending multiple signals on the same carrier causes interference. Therefore interference is not a problem of scarcity but rather a result of *confusion* by receivers that cannot distinguish signals from noise (Reed 2002). So a frequency can be used by multiple users if their receivers can identify signals.

On the other hand, spectrum has limited capacity. According to Shannon's Channel Capacity Formula, the channel capacity C (bits per second) is limited by the bandwidth, B (Hertz):

$$C = B \log_2 (1+S/N),$$

where S is the power of the signal (in watts), and N is the noise level (W/Hz). In analog radio, as it is impossible to distinguish signals of the same frequency, spectrum should be divided into small portions to avoid interference. And, since N is given physically, the only way to do this is to magnify S to discern signals from noise. Thus radio signals are sent in narrow bands and at high power to large areas. If B is divided into small portions of equal size, $b_1, b_2, \dots b_n$ and allocated to each licensee, each licensee can get at most C/n of capacity. The inefficiency of this *high power and narrow band* radio system did not matter when radio equipment was very expensive and a small part of the spectrum was utilized, but it is posing serious problems today.

Cellular phones depend on the circuit switching in which each user occupies a band exclusively even if no signals are transmitted. A digital wireless technology called *packet radio* extends B by sending different packets in a band. Because packets are identified individually, interference can be avoided even if multiple signals are carried in the same frequency. Spectrum is used efficiently by *statistical multiplexing*, which levels traffic in a wide band. As average traffic usually represents a very small portion (less than 10%) of the maximum capacity, if 100 users share a bandwidth of 20 MHz, more than 2 MHz is available for each user on average. This is obviously more efficient than allotting 200 kHz across 100 users.

If B is large, it is not necessary to magnify S to increase C. Lowering power makes it possible to multiply spectrum by establishing many stations. This *low power and wide band* system makes digital radio more efficient than traditional broadcasting systems. The problem is thus not the *scarcity* but the *efficiency* of spectrum usage. Therefore, bandwidth can be better utilized as commons, shared by many WLAN terminals. If a wide band can be shared by many users identifying signals packet by packet, this will be much more efficient than dividing spectrum into narrow bands and selling them to individual users.

A packet radio technology called *spread spectrum* has been widely adopted to send various packets in a band while avoiding interference. In the direct-sequence spread spectrum (DSSS) adopted in WLAN, transmitters multiply original signals (baseband) by *pseudo-noise* (encryption key) and spread the resulting signals into thin waves over a wide band using weak power. Receivers decode the airwaves by inverse spreading, in which the signals are multiplied by the inverse pseudo-noise. By multiplying and dividing the baseband by the same number, this process recovers the desired data but scatters the noise thinly to allow its elimination by filters.

Thus it is not necessary to separate frequency to prevent interference. A number of users can use full bandwidth by multiplexing and identifying individual packets by their spread codes. Spread-spectrum technology was invented during World War II to prevent interception and electromagnetic jamming of military communications. It was later adopted for communications in the unlicensed band (2.4 - 2.5 GHz) to prevent interference from other devices such as microwave ovens. This band is called the ISM (Industrial, Scientific, and Medical) band, because it was originally released for unlicensed use by hospitals, factories, and so on, rather than for communication purposes.

WLAN technology, standardized in the 802.11 Committee of the Institute of Electrical and Electronics Engineers (IEEE), initially attracted little attention because its speed was only 2 Mbps. But after the enhanced mode IEEE 802.11b (Wi-Fi) was standardized in 1999, WLAN exploded; within a few years the number of users worldwide grew to more than 30 million (2002 figure). This is because 802.11b realized up to 11 Mbps (3-4 Mbps on average) by sharing the wide ISM band (22 MHz per channel)[1]. In contrast, the speed of data communications in current 2-G mobile telephones is around 10 kbps due to bandwidth limitations. For example, the PDC adopted in Japan allocates only 25 kHz (12.5 KHz in "half-rate" mode) per user.

Multiplexing by Space, Time, and Power

The method of multiplexing airwaves for many users is not limited to frequency. Shannon's Formula represents the limit of capacity in a given place, but it can be extended by multiplying stations because different users can use the same band repeatedly in separate places. This is the cellular technology by which mobile telephones enhanced bandwidth over traditional usage. The WLAN band is separated into a number of channels, which are allocated to each low-power station. As shown in Figure 2, channel A can be used repeatedly by dividing an area into many *microcells* in which each user can utilize full capacity without interference from other terminals. If the band is wide enough to allow division into many channels, theoretically, the capacity can be multiplied infinitely by dividing an area into an infinite number of cells.

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[1] WLAN spreads the same signal several times, so the transmission efficiency per frequency of 801.11b stands at 11 Mbps/22 MHz = 0.5, similar to that of cellular telephones.

Of course, the overhead cost of connection between base stations will limit the number of cells in reality. But if they can be connected by wireless networks, this cost could be reduced. For WLAN terminals to be used as base stations in *ad hoc* mode, completely distributed multi-hop networks called *wireless mesh*, which link terminals to each other directly, can be built by WLAN terminals. If the price of WLAN chips falls to several dollars – as is likely in a few years – they will be incorporated into a wide range of devices that can communicate with each other.

In this regard, WLAN is even more revolutionary than wired Internet. TCP/IP is characterized by the architecture referred to as End-to-End (E2E), which means that the communication is controlled only by senders and receivers. In the wired Internet, however, routing and addressing are mostly performed by Internet Service Providers (ISP) because networks are built on the telephone-type topology. WLAN has deconstructed the centralized architecture and enabled completely decentralized E2E structures physically. Such *ad hoc networks* have been built throughout the world by volunteer organizations.

Public networks can be built by linking local wireless networks called *hot spots* in restaurants, hotels, airports, and so on. But the quality of the 2.4-GHz band is unsatisfactory. Industrial dryers, medical equipment, and different types of communication terminals such as Bluetooth interfere with WLAN. And the bandwidth (less than 100 MHz for 4 channels simultaneously) would not be sufficient if many operators built base stations in the same place. The quality of the 5-GHz band is higher than that of the 2.4-GHz band, although the higher the frequency (i.e., the shorter the wavelength), the heavier the attenuation, and the more vulnerable communication becomes to obstacles.

In the United States, 300 MHz is available within the Unlicensed National Information Infrastructure (U-NII) band at 5-GHz band. The European Union is planning to open 580 MHz for HiperLAN without a licensing requirement, which can be divided into more than 25 channels in which up to 54 Mbps can be transmitted in each channel with IEEE 802.11a. In Japan, however, there is no unlicensed outdoor band at 5 GHz; only 160 MHz is available by license and 100 MHz is available indoors without a license.

There is another dimension by which we can utilize spectrum efficiently: time. For example, meteorological radars occupy 5.25-35 GHz, but they use the band for only a few minutes per hour. If other terminals can sense the radar waves and stop using the channel while the radar working, they can work together in a channel. Such adaptive technologies, known as *agile radio,* have been standardized and implemented into some 802.11a chipsets. Dividing bandwidth by time, these technologies enables WLAN base stations to coexist with other terminals in a band and realize much more efficient use of idle spectrum. For example, 300 MHz of the UHF band is allotted to TV stations, but less than a half of it is used in Japan. So if WLAN terminals equipped with cognitive radio technologies can detect vacant channels and use them, more than 100 MHz of spectrum can be "created." If such *overlay* usage is allowed in all bands, available bandwidth will be so large that its allocation would not be necessary.

Software-Defined Radio (SDR) will make such adaptation even easier by changing physical layers by software, just like applications for PCs. And *smart antennas*, combining various antenna elements with a single processor, can change the transmission/reception mode in response to the communication environment. If a channel is occupied by 802.11a, other terminals can change its modulation to 802.11a by SDR. To deploy SDR, however, regulatory reforms will be necessary: the present Radio Act bans non-standardized communication devices by certification of equipment, but if communication is performed by software, it would make no sense to certify the equipment.

There is yet another dimension of multiplexing: power. Part 15 of the Code of Federal Regulations defines the admitted noise level for unlicensed devices. Ultra-Wide Band (UWB) is the technology to use such very weak signals that cannot be distinguished from the radio noise generated by TVs, computers, and hair dryers. In contrast to the conventional radio technology that modulates baseband with a carrier (sine curve), UWB modulates the baseband with very short pulses (less than a nanosecond). This technology realizes high-speed transmission (up to 500 Mbps) by emitting pulses in a wide band, over a frequency range of several GHz. Since their waveforms are completely different from those of conventional radio waves and are emitted at very low power levels, advocates of UWB claim, the system will make overlay use possible over all bands without interference. In fact, however, interference was found in experiments conducted by the FCC. In February 2002, the FCC authorized UWB with very conservative restrictions for its band (above 3.1GHz) and with weak power. Therefore, for the time being, use of UWB will be limited to indoor use.

Regulatory Reforms

These radically new technologies are demanding a "new spectrum policy paradigm" according to the FCC Chairman Michael Powell (Powell 2002). To cope with these changes, Noam (1998) proposed a reform named *open access*. If you allocate bandwidth dynamically, this will be far more efficient than the current system of static allocation. If demand is lower than capacity, everybody can access bandwidth freely. If demand exceeds capacity, a "clearing house" charges fees for wireless traffic, acting as a tollbooth. It is much harder to charge for airwaves than for cars because the former do not pass through specific gates, so this proposal has been regarded as unrealistic. However, digital technologies such as spread spectrum have now rendered this idea feasible.

If bandwidth is supplied to an extent greatly exceeding demand, open access will become possible without fees. Even if bandwidth did not exceed demand, the allocation of packets by spread spectrum would be more efficient than charging for packets. Packets in the wired Internet are stored and forwarded by routers without charge. Congestion leads to waiting, but this is not a very serious problem in data communications and can be overcome by widening the bandwidth. Already, we can reach up to 108 Mbps by using two channels of 802.11a together. UWB has realized 500 Mbps and its capacity will easily extend to more than 1 Gbps.

Thus rivalry of spectrum among multiple users can be eliminated using packet radio technologies, which increase capacity by adding stations and terminals. If a resource is neither rival nor excludable, it should be supplied as (pure) *public goods*. A typical example of public goods is national security. Since there are no economic problems of resource allocation with such services, a "market-oriented" approach does not make sense. Instead, in the long run, the spectrum should be maintained by public administration which makes rules and enforces them by monitoring abuses.

"Public" does not necessarily mean "governmental." The concept of commons is so old that it has been preserved by the social norms of the community without any government regulation. It is the destruction of social norms by Western companies that incurred the large-scale abuse of tropical rainforests. Today the commons of the Internet is preserved by hundreds of millions of users worldwide without any government control. Standardization of radio equipment by the government has ended with the failure of 3G. Today, such non-profit organizations (NPO) as IEEE and the Internet Engineering Task Force (IETF) have taken over the role of the ITU.

Of course, this does not mean that government regulation is unnecessary. Even if there is sufficient bandwidth, interference will occur between different physical layers. One way to prevent such interference is to fix a physical layer (modulation) for each band; for example, 802.11b for 2-3 GHz and 802.11a for 3-6 GHz. Some argue against unlicensed usage because such physical regulation will impede innovation (Hazlett 2001), but regulation is not necessary for this purpose. For example, if a channel is occupied by Bluetooth, WLAN can use another channel by sensing the carrier. If there is sufficient bandwidth and flexible technologies such as agile radio are deployed, various physical layers can coexist in different channels.

To coordinate various kinds of terminals to work cooperatively, regulating channels, powers, frequencies, and modulations of different terminals will be the important task of radio administration. Traditional regulation has focused on transmitters, but it is necessary to regulate receivers to control interference among different types of terminals. Since digital receivers are much more tolerant of interference than analog ones, there should be more flexible criterion *interference temperature*, according to the FCC's term, to enable different systems to coexist in a band.

Such regulation should be enforced not for operators but for manufacturers because communication terminals will exist as ordinary electronic appliances independent of operators and service providers. The standardization can be left to the NPO, but the certification of equipment and monitoring of abuse should be carried out by the government. Without such supervision, unlicensed bands tend to bring about a "tragedy of the commons" as recently evidenced by the 2.4-GHz band. Although it is most important to supply sufficient capacity to render abuse unnecessary and harmless, surveillance and enforcement will have to be intensified, at least transitionally.

3. Reverse Auctions

Strategy for Transition

During the transition period, licensed and unlicensed bands will coexist, but the criteria by which the spectrum rights are specified should be determined not by the so-called scarcity but by the excludability (efficiency of exclusion) of a band. Above 3 GHz, it is pointless to exclude spectrum because there is no new technology that depends on frequency division in that band. Exclusion might be justified in the extremely lower band (probably below 30 MHz) where high-power propagation is economical and no digital radio technology is likely to be implemented. In the intermediate band, the *easement* of overlay usage should be enforced.

Thus a strategy of transition to more efficient technologies is necessary. As SPTF insists, spectrum policy must "provide incentives for users to migrate to more technologically innovative and economically efficient uses of spectrum" (FCC 2002: p.15). To achieve the goal, however, it seems that the FCC is going to give spectrum away to incumbents as their private property and let them use it efficiently. At the same time when the SPTF report was published, economists at the Office of Plans and Policy of the FCC published a working paper to prescribe the "Big Bang auction" that would enable incumbents to sell and buy all spectrum freely (Kwerell-Williams 2002).

Indeed this system would be politically easy to accomplish because it is so advantageous to incumbents. However, there would exist a danger that exclusive rights would authorize incumbents to exclude other parties' more efficient usage. If spectrum were sold at a high price, the "owner" of spectrum would maximize its value by monopolizing it. This is rational behavior for individual users, but it would lead to socially inefficient outcomes. Even worse, such a policy is irreversible; once spectrum is given away to incumbents, spectrum commons would be lost forever because incumbents would never open it. Easement would be harder to enforce because incumbents would resist such "regulatory taking" of their private property.

Legally governments can take back the spectrum when licenses expire. The Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT) of Japan announced a plan for such ruling in November 2002. MPHPT is going to rule that, if licenses expire, licensees must return their spectrum with compensation for the remaining book value of their equipment. Because the term of license is five years and the term of amortization is six years, the average licensee's remaining value is very small. This is legitimate but difficult to enforce. If incumbents resist, it would take a long time to evict them by negotiation; MPHPT estimates that it would take 10 years to clear the 4-GHz band. Worse, many incumbents would refuse the "taking" of spectrum on which their business depends and regulatory nightmare would result.

Such a problem can be resolved by breaking it down into two parts; it is necessary to motivate incumbents to exit by compensation, but it is harmful to admit them exclusive rights for the spectrum. So it is advisable for the government to take back the spectrum through *reverse auctions* and then open the acquired spectrum without a license requirement[2]. This mechanism can be implemented as an ordinary procurement process by which the lowest bidder sells goods to the government.

Auction Design

The government should "clear" a band by taking back all the stations in the band nationwide, but it would not be necessary to open all spectrum because 1 GHz might be enough to supply the bandwidth for WLAN in current use. As it is difficult to compare the value of different bands, the government is advised to focus on specific bands. In Japan, the best candidates for WLAN band are the 3-5 GHz used for business-use communications and the backbones of mobile telephone networks. The procedure would be as follows:

1. The government announces the required minimum bandwidth, the target band, and the budget.
2. Bidders register their prices to sell their spectrum via computer network. The bids will be known to all bidders through the network.
3. As long as there are new bids, the government continues to lower the price.
4. If no bid is registered, the auction is over.

Because simple maximization of bandwidth may result in fragmentation of the band into many small pieces, there should be a requirement on bands; for example, the band should be continuous more than 50 MHz. Government can maximize the bandwidth per budget by buying the spectrum of all stations in the band in which aggregate price is the cheapest. Suppose the budget is 2 billion yen and aggregate bidding prices for each 10 MHz band in 4.00-4.10 GHz are as shown in the following Table:

4.00	01	02	03	04	05	06	07	08	09	10 GHz
.4	.3	.1	.8	.7	.3	.3	.4	.2	.4	.6 billion yen
←		→			←			→		

Table: Bids for the band groups

In this case, government can maximize the bandwidth per budget by buying the spectrum of all stations in 4.00-4.02 GHz with 0.8 billion yen and 4.05-4.08 GHz with 1.2 billion yen. Stated generally, the objective function of the government is to maximize (in a given range) the total bandwidth $W = \Sigma_i w_i$ ($i = 1,2,\ldots n$) that aggregates the individual bands w_i, within which the aggregate price $P_i = \Sigma_j p_{ij}$, where p_{ij} is the jth bidder's price within the ith band, subject to the condition

$$w_i \geq r,\ \ \Sigma_i P_i \leq y$$

where r is the required minimum continuous bandwidth and y is the budget. This specific procedure is due to the requirement that the unlicensed band should be opened in as large a block as possible. Other requirements are possible: for example, there should not be more than three fragmented bands or wider bands should be evaluated with some premium.

An important characteristic of this auction is that the *aggregate* price within each band group is compared. So the band that includes the least number of incumbents is likely to win even if the individual member's bid is higher than the other band. Conversely, if bidders know the number of participants in each group, they will minimize the aggregate price of the group to which they belong, instead of their individual prices. To avoid such a problem, the government can "normalize" the prices, for example, by distributing the average price per MHz to all incumbents in the winning bands.

With such adjustments in place, bidders will have little incentive to offer a higher price than the true value, because they bear the risk of losing the bid, while the gain will be equally distributed among all bidders in the group. For example, if the 4.05 GHz group raises its price by more than 0.4 billion yen, they will be outbid by the 4.09 GHz group. Collusion in this auction would be difficult because the boundaries of winning bands are variable. If a group of incumbents succeeded in lifting its aggregate prices, it could shift the boundary.

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[2] As a complementary mechanism to patent licensing, Kremer (1998) proposed a mechanism called the "patent buyout" in which the government buys patents from inventors through auctions and opens the patents to everyone.

Because competition will be effective in a band where many incumbents are evenly distributed, governments are advised to have auctions in such well-organized bands. If these auctions are repeated, the least populated bands will be vacated and the next least populated will be the winner. Thus, incumbents in a densely populated band will not join the auction in the earlier stages. As a result, we can expect the bidding price to be roughly equal to the bidder's own valuation of spectrum, though it would be safe to conduct experiments along these lines before execution.

Some have argued that such an auction would be extremely costly, referencing the prices of PCS auctions, but this would not be the case. In an ordinary spectrum auction, an *ascending* English auction, the equilibrium price is equal to the net present value (NPV) of the *most efficient* use of spectrum. On the contrary, in a *descending* English auction, the equilibrium aggregate price is approximately equal to the opportunity cost of the *least efficient* use of spectrum on average.

The opportunity cost for a bidder includes the remaining asset value of equipment plus the net present value (NPV) of the profit that would be gained by using the spectrum. Usually NPV is determined by future cash flow, terms of license, interest rates, tax, and so on. However, even if an incumbent returns the spectrum, it can do the same business over wireless Internet when the spectrum is opened. In such a case, the profit would be lower because the market for the same services is more competitive. Thus, the NPV is the discounted value of monopolistic rent that would be smaller than the usual NPV.

Ignoring the interest rate and tax, I denote the opportunity cost of the least efficient user k as $Q_k(x) = V_k(x) + z_k$ where V_k is the NPV, x is the term of expiration, and z_k is the remaining asset value (supposed as a constant). If the government can credibly threaten incumbents to return the spectrum, or at least if there is uncertainty as to the duration of the license, this buyout would be more effective. Suppose $V_k(x)$ is subdivided into the cash flow v_j in each term. If the rule of returning is enforced in the second term, $Q_k(x) = v_k + z_k$. If it is enforced at probability q every term, the opportunity cost will be

$$Q_k(x) = v_k + (1-q)v_k + (1-q)^2 v_k + \ldots (1-q)^x v_k + z_k.$$

If x approaches infinity, $Q_k = v_k/q + z_k$. So the equilibrium price p^* will be

$$p^* = v_k/q + z_k.$$

If enforcement becomes more likely, q will approach 1, then p^* will approach $v_k + z_k$; the one-term profit plus the remaining book value of the least efficient user. Moreover, as v_k is the NPV of the most poorly operating incumbent's monopolistic rent, its value will be very small if reverse auctions are properly designed. Even if an inefficient incumbent refuses to join an auction, its monopolistic rent will deteriorate when entrants do the same business over WLAN using the opened band. Therefore, if sufficient bandwidth is opened without a license and incumbents are rational, we can suppose $v_k = 0$. This result coincides with the plan of MPHPT, which takes back spectrum while compensating for the remaining book value, that is, $p^* = z_k$. The difference is that the idle spectrum can be taken back right now in our mechanism. Thus, I recommend this reverse auction as an *optional* mechanism that incumbents can choose, together with a strong commitment that, after the government acquires the spectrum, it will open enough spectrum to wipe out monopolistic rents.

On the other hand, once the band is made private property, as is planned by the FCC, q will approach zero and v_k will increase because this becomes profitable; therefore p^* will be much higher and a buyout will become more difficult. That is, the "privatization" of spectrum makes it difficult to open it without a license. If it were possible to suppress the rent and make spectrum commons by regulation in the end, as Faulhaber-Farber (2002) claims, no one would buy the spectrum that would eventually be worthless. In other words, as it is inevitable that the value of spectrum will disappear if the wireless Internet prevails, the NPV of every spectrum would approach zero in the long run. It would be pointless to buy such a worthless asset or sell it at auction.

Public users cannot be bidders, but they should be compensated for the cost of converting equipment or of exiting. Their bands should be evaluated as the average of the nearby bidders. Another problem would be posed by whether or not a public band should be sold; for example, the band used by air traffic control could not be sold by the market mechanism.

4. Discussion

Spectrum buyouts may arouse controversy. Some would oppose this reform as an unfair income transfer for incumbents who are underutilizing allocated bands. I argue that, following the Coase Theorem, it is much more efficient to "bribe" incumbents to return their idle spectrum than to negotiate with them over a long time. The opportunity cost of wasting bandwidth and time would be much more expensive than the cost of buying the band back. In my scheme, the government does not have to negotiate with incumbents and politicians but only has to announce the reverse auction. Incumbents will bid and reveal their valuation of spectrum, and winners will give back their bands even if they are using them, as they would be reimbursed for the cost of replacing their old stations and terminals with WLAN.

Some argue that there is no need for buyouts if the overlay use of spectrum is admitted; if every terminal could use all idle bands dynamically, it would make no sense to reallocate spectrum at all. While this is true, agile radio is so complicated and expensive that it has not yet been implemented in portable terminals. To avoid interference, agile radio terminals should store detailed data of other equipment's characteristics such as the power, direction, and timetables of radar. This represents not just a technical but a regulatory challenge. Overlay use of different modulation systems in the same band requires complicated regulation of devices, which regulators are reluctant to enforce. UWB was at last authorized by the FCC in 2002 after 20 years of negotiation.

It is naïve to suppose that incumbents will admit the easement of overlay if it does not interfere the incumbent's communication. Since massive entrance will threaten their monopoly profits, incumbents will resist easement in their spectrum under the pretext of interference, as evidenced in the case of UWB. In such cases, the FCC can have "overlay auctions" to compensate incumbents for allowing easement of overlay usage. In the long run, this would be equivalent to the reverse auctions because incumbents will renew their equipment that can be used as overlay. So rational incumbents would be willing to sell their spectrum and change their stations and terminals with the auction fees.

The reverse auction is, as stated above, not a substitute for overlay use but a complementary strategy to facilitate transition in the band required for WLAN. Opening a clean band is obviously better than easement, so the problem is which is the faster and cheaper method for opening spectrum. This will depend on various factors such as progress in radio technology, the political power of incumbents, and so forth. My guess is that, at least in the band above 3 GHz over the next 10 years, buyouts will prove to be the faster way. It would not be cheaper, but it could buy precious time by "bribing" incumbents. This might work as a middle-of-the-road solution between the commons approach, which is economically efficient but politically difficult, and the exclusive rights approach, which is inefficient but easy. Both incumbents and entrants can benefit from this buyout, and we can open spectrum as commons through a market mechanism.

Financing might be the most difficult part of this reverse auction because the fee would be much larger than in usual procurement cases. A simple solution would be to finance the auction through general government accounts, in view of the fact that governments have made a great deal of money by auctioning off spectrum to private parties. This would cure the problem of spectrum auctions raised by Noam (1998): auctions "tax" the communications industry and suppress investment. Through such repayment the government can revitalize wireless operators, which lost a great deal of money in the collapse of the bubble. It is, in effect, a collective auction by WLAN users, so its cost is equivalent to that of an ordinary spectrum auction, in which the winner will pass on its costs to consumers.

Another solution, probably better suited to Japan, would be to compensate the government's cost of reverse auctions through *spectrum usage fees*. This would be more neutral to public finance, and raising the fee would press incumbents to use bandwidth more efficiently or to sell out. The present tariff of spectrum usage fees in Japan, however, is a disincentive for efficient use of bandwidth: because the fees are charged in proportion to the number of radio stations, more efficient users are charged more. If the fee is charged for bandwidth, this will offer incentives for efficient bandwidth use. As these financing methods are complementary, governments could use them in combination.

The greatest risk might lie in having the government conduct such a gigantic auction. It is possible that irrational behavior (as was seen in 3-G auctions) might lead to extreme behavior and unexpected results. If sellers rushed to sell their bands as soon as possible, the price would be near zero, but such mistakes would be harmless for the government. If sellers were to collude to keep the bidding high, the government would have the option to quit. Rent seeking and collusion would be most effective because the stakes are so high. It would thus be necessary to perform preliminary experiments before the buyout and to keep the procedure transparent. Further, governments would need to exit from spectrum management after all spectrum had been opened.

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