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Modified Lease Auction and Relocation---
Proposal of a New System for Efficient Allocation of Radio–spectrum Resources[1]

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Abstract

The objective of this paper is to propose a system by means of which the utilization of radio spectrum may be improved from the state of extreme inefficiency at the present time to a state of equilibrium and efficiency in the future. The paper attempts to introduce a system which takes advantage of market mechanism as much as possible. It is composed of three parts.

The first part proposes a system called "modified lease auction (MLA)," in which the government, the sole owner of spectrum, leases (rents) it competitively to business and public users. Thus, not only initial but also successive licenses for the use of spectrum are assigned by auction on lease prices; this will increase the efficiency of spectrum utilization. A serious disadvantage of lease auction is that the incumbent spectrum user faces the risk of discontinuation (ROD); i.e., the user may not be able to continue to use the same spectrum that was used previously. To protect incumbents from excessive ROD, the paper proposes a number of ways including, but not limited to, a provision of insurance.

The second part proposes a system for the long-run allocation of spectrum. The government simulates the functioning of competitive markets for this by using the data including lease prices and insurance amounts generated in MLA. Further, a provision is introduced to consider "spectrum commons" as a public good to have their opportunity cost

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revealed so that not only exclusive but also shared use of radio spectrum may be managed under MLA.

The third part of the paper considers the process of transition from the current system to MLA. The paper proposes a process in which the spectrum price be increased gradually from the current level, which is essentially zero, to the target equilibrium level. Further, in order to reconcile to possible oppositions by incumbents to MLA, a scheme is proposed for compensating income to incumbents without hurting the incentive to save spectrum.

Contents:

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C. Gradual increase in lease prices during the execution period

D. Income compensation

References

Figures

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I. Introduction and Background

The objective of this paper is to propose a system by means of which the utilization of radio spectrum may be improved from the state of extreme inefficiency at the present time to a state of efficiency and equilibrium in the future.

We will propose a system to be called "modified lease auction (MLA)," in which the government retains the ownerships of radio spectrum but leases it to users according to auction on lease prices. In order to remedy shortcomings of the lease system, a number of modifications will be introduced to it, hence the naming of modified lease auction. Lease prices are used by the government for making adjustments in the allocation of spectrum bands in the long run as well as for assigning spectrum blocks to users in the short run.

In the last part of this paper, a scheme will be proposed for gradual transition from the present state of spectrum utilization with zero price to a state in which the market price prevails. In addition, in order to reconcile to political oppositions by incumbent spectrum users, a provision for income compensation will be introduced so as to protect incumbents in their income on the one hand, but not to lower the efficiency of spectrum utilization on the other.

Radio spectrum in Japan, as in other countries, was first used about 100-years ago for navigational safety and navy operations. Since that time, the utilization of spectrum has expanded steadily and greatly. In the 1920s, voice radio became popular, and in the 1940s, during the War, radar was invented. After the War, in the 1950s, television receivers, first black and white and then color, became a major household good. Today, in many countries, mobile telephony shows a penetration exceeding one-half of the population and spectrum is used widely for many other purposes.

Such remarkable development of the utilization of radio spectrum was achieved, needless to say, by a succession of technological advances. Typically, a new technology was introduced by making use of a new "band" of radio frequencies which had so far been unused; that is to say, the development process was an expansion of the frontier of spectrum utilization. The issue to be dealt with in this paper arises from the fact that such frontier is nearly exhausted today.

During the course of this process, the administration of the use of radio spectrum was

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under the direct command and control by the central government in almost every country. For one thing, the major concern was how to prevent interferences between spectrum users; this called for public regulation. For another, spectrum was first used for safety and security ; it was natural for the government to play the role of managing it. Furthermore, since new utilization of spectrum was made possible by the expansion of spectrum frontier, spectrum scarcity was not a major concern; the government was able to award the right to use spectrum without troubles.

Thus, until recently, the principle of command and control by the government prevailed in spectrum utilization. The government first determines that a particular band of frequencies be used for a specified purpose, and then assigns it to users on the first-come basis or by discretion. In Japan, as in many other countries, there has been no rent charged by the government from spectrum users except nominal fees for the cost of administration. In short, the world of radio spectrum has been a socialistic island under the governmental command and control in an ocean of economic activities under market mechanism.

This situation, however, changed in the 1990s. As the speed of technological progress was increased, the demand for radio spectrum grew exponentially in vision of new services such as mobile telephony and wireless Internet access. Roughly speaking, at the beginning of the 21st century, the frontier of economically usable spectrum was nearly exhausted. The present situation is such that we are unable to find a frequency band for new services in the same way as we were able in the past.

It should be noted, however, that, while the frontier may have been exhausted, it does not mean that there is no way to find additional spectrum for new services. There still remains a great many opportunities of increasing the supply of spectrum by means of *relocation*. A large portion of the spectrum bands which have been allocated and assigned to users remains unused or used very inefficiently. During the time of frontier expansion, it was of little concern for the government to have spectrum used efficiently. Furthermore, it was not a concern of users either to save spectrum since the price was near zero, except with such users as mobile telephone operators for which the supply of spectrum was insufficient relative to their need. As a consequence, the state of utilization of radio spectrum at the present time is in extreme disequilibrium; some spectrum is used efficiently with a large amount of expenditure

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on new equipment, but other spectrum is used inefficiently with old and obsolete equipment. This situation may be compared to a case in which large farmland is found within the City of London or next to the Empire State Building in New York. Such a case in the use of land would be precluded by the market power. For radio spectrum, we do have extremely unbalanced utilization, since the market power is not working.

The challenge we face today is to find a way to get out of such inefficient disequilibrium. Since the frontier has been exhausted and the utilization remains unbalanced, some relocation of radio spectrum between incumbent and new users is unavoidable. There are, however, several factors which make relocation of spectrum under the governmental command and control extremely difficult.

First of all, the need for relocation depends on technological progress which increases the efficiency of spectrum utilization. Since, however, the speed and the cost of technological progress cannot be predicted precisely, there will always be uncertainly as to what would be a desirable extent of relocation.

Second, there will be strong opposition to relocation of spectrum by incumbents, who have been using spectrum free of charge for years and have vested interest in it in the form of equipment, devices, and other investment. A consequence would be irresolvable disputes on relocation among incumbent and new users of spectrum.

On top of these, the presence of technical and other regulations on the use of spectrum increases the difficulty of relocation. The regulations are complicated and many of them are outdated because of the rapid progress of technology in the past. It would be difficult to evaluate a relocation plan in the presence of complicated regulatory environment. It would be more difficult to do so if the *issue of improving regulations itself* need to be taken into consideration. Because of these factors, spectrum relocation in many countries tends to become not only a regulatory issue but also a political conflict on which it is difficult to reach an agreement.

The objective of this paper is to propose a system for improving the efficiency of spectrum utilization by means of relocation. In view of the above observations, we will adopt the following strategy for the presentation in this paper. First, we concentrate on economic aspects of spectrum utilization and relocation. By this we mean that we do not deal with the

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issue of improving technical regulations; we take them as given in our discussion. This does not mean, however, that there is no need for improving technical regulations; on the contrary, we think there is a strong need for it. We only try to separate economic considerations from technical ones.

Next, it will be one of our main concerns to propose a system in which the benefit of technological progress be fully materialized and the incentive to promote technological progress be maximized. This paper, however, is not concerned with evaluating or recommending a particular technology for spectrum utilization. The author of this paper agrees that new technologies for sharing spectrum (such as spread spectrum, overlay, ultra-wide band, and software-defined radio) may greatly improve the efficiency of spectrum utilization in the near future. The objective of this paper is to propose an economic system in which superior technology, for shared or other use, be adopted as soon as possible through competition, not through the governmental command and control.

In the following section, Section II, a summary will be given of the economic properties of spectrum resource and of the system of spectrum utilization at the present time. In Section III, the system of modified lease auction (MLA) will be presented. It is noted that MLA can accommodate various modes of spectrum utilization such as exclusive use, club use, and commons use. Section IV presents a system for the government to relocate spectrum bands on the outcome of MLA by simulating market mechanism. Finally in Section V, a scheme for transition from the present system to MLA is presented. It is composed of two procedures. One is a stepwise increase in the lease price from the present level of zero price to the equilibrium market price. The other is a scheme for income compensation.

II. The Present System of Spectrum Utilization

A. Outline

In this section, we first summarize the economic properties of radio spectrum, which will be considered as one of space resources. We then proceed to explaining the present system of spectrum utilization. The proposal to be made in this paper would greatly change, on the one hand, the substance of spectrum utilization in that it introduces lease auction and

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other market elements to replace command-and-control decisions by the government. On the other hand, as explained in the preceding section, the proposal will be presented in such a way not to change much the formality of spectrum utilization given by technical regulations. Therefore, it will be useful to give a perspective of the formality in which radio spectrum is utilized at the present time and then to make clear at which points within this formality the proposal of this paper intends to introduce changes.

B. Spectrum as an economic resource

Radio spectrum is a non-reproducible natural resource. It is different from oil or mineral deposits in that it does not deplete. It is different from produced capital in that it does not depreciate. Radio spectrum, however, is not a resource of unlimited supply. As such, radio spectrum in many respects resembles "land" as real estate. In fact, radio spectrum as an economic resource may be classified into a category of *space resources*, of which examples are land space, water space, air space, the space of satellite orbits, to name a few. The term "spectrum" means, in many cases, the *space* for having radiowave of designated frequencies propagate.[2] [3]

Radio spectrum is used for many purposes; communication is a major, but not the only, one. In order to use radio spectrum, we always need to prepare some capital stock such as equipment, devices, software, and others.

Technology plays an important role in using spectrum. Technological progress makes it possible to improve or invent capital stock (e.g., communications devices), thereby increasing the *capacity* of spectrum utilization (e.g., the capacity for data transmission). For example, spread spectrum, a technology to increase the communications capacity of spectrum, may be compared with skyscraper buildings, a product of technology to increase the capacity of land for office and other use.

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2 It is sometimes stated that the government has no right to regulate the use of radio spectrum for the same reason that the government has no right to regulate the use of red or green light, both being a range of electro-magnetic frequencies. This is correct but irrelevant. The actual object of regulation is not the right to use spectrum itself but the right to use *a space* for radiowave propagation.

3 In general, a space has a dimension to represent the number of independent axes and a measure to represent its "size." Physical spaces such as land and water (surface) spaces have two dimensions and air space three dimensions. The satellite orbit is a one-dimensional space. Terrestrial spectrum spaces may be considered to be of three dimensions, since, to the two dimensions used to designate an area on the earth, we add one dimension for frequencies.

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In fact, using radio spectrum can be viewed as an activity for producing a service such as mobile telephony and Internet access. In this activity, spectrum and capital stock are substitutable inputs; a given quantity of service can be produced with different quantities of spectrum and capital stock as represented by a curve in Figure 1; the shape and the location of a curve is determined by the technology being used for production. ***Insert Figure 1 here.***

Suppose, for example that a mobile-phone provider with old technology operates at point P by using up the assigned spectrum at B*. With the introduction of new technology, the curve may be shifted downward, and the provider could save spectrum by operating at Q. At the present time, however, the price of using spectrum is zero, and the operator would choose point R to save capital investment instead (or to increase service production with given capital investment). Thus, there is no incentive for the provider to save spectrum under the present system of zero price.

It may be convenient to summarize briefly some of the economic characteristics common to land and spectrum (and to space resources in general). First, both land and spectrum can be used in various modes including exclusive use, club use, and commons use. A land space for residence is used exclusively, while streets and city parks are examples of commons. We will consider different modes of spectrum utilization in detail in the following subsection (II.C).

Second, space resources exhibit economies of scale; that is, there are cases in which doubling the size of land or spectrum returns more-than-doubled outcome. For the case of land, an example of economies of scale may be seen in the traffic capacity of highways; the capacity of a two-lane highway is greater than twice of that of a single-lane one, and the capacity of a three-lane highway is greater than one-and-half times of that of a two-lane one. Similar examples may be found with land space used for buildings. The benefit obtained by sharing spectrum by means of spread technology is an example of economies of scale in spectrum utilization.

Third, space resources have external diseconomies in that excessive use of a space lowers the return; such a case is called “congestion” in the use of land and “interferences” in the use of spectrum.

Forth, we note that, in general, a space resource may be in the state of short supply or

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of excess supply. For example, there are excess supplies of land in rural areas, whereas the supply is tight in cities. Similarly, spectrum is scarce in urban areas, but not so scarce in rural areas. The state of a space resource with regard to “supply tightness” depends on the demand for it, the size of the space as given by Mother Nature, and the technology for using it. Spectrum utilization has become an important issue, since the demand for spectrum grew faster than the advancement of technology, which can increase the efficiency of spectrum utilization.

Lastly, a major difference between land and spectrum at the present time is that a large portion of land is used under market mechanism in most countries, whereas the use of spectrum is under the command and control by the government. The command and control mode worked well at the time when the supply of spectrum resources was abundant relative to the demand for it. It is obsolete at the time of spectrum scarcity, as agreed upon widely (e.g., FCC[2002]). The objective of this paper is to propose a system dealing with spectrum scarcity by using the power of market mechanism as far an extent as possible.

C. Allocation of spectrum bands

The utilization of radio spectrum at the present time is administered by the government in two stages; the first stage is the allocation of spectrum bands for specific purposes (to be called *ALLOC* in this paper), and the second stage is the assignment of spectrum blocks to users (*ASSGN*). .

The ALLOC stage specifies *spectrum bands* and the ASSGN stage subdivides a band into *spectrum blocks*. A band is a range of radio frequencies given one or more objectives for which it is to be used. An example of ALLOC and ASSGN is given in Figure 2[4]. As the objective for spectrum usage, it gives “Broadcast” for band A, “Commercial Mobile” for band B, and so on. An overall specification of spectrum bands is determined by the International Telecommunications Union (ITU) in order to facilitate international coordination of spectrum utilization. The government of each country may specify a band and its objective in more detail within the framework determined by ITU. ****** Insert Figure 2 here. ******

Occasionally, we introduce a secondary objective for using a band; in that case, the right to use the band is divided according to *priority* into two, the right on primary basis and the right

[4] ALLOC as a regulation on spectrum space resembles with “zoning” as a regulation on land use.

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on secondary basis. A primary user has the same right as given in the absence of a secondary user. A secondary user can use it within the restriction not to disturb the primary user and to accept any possible disturbances from the primary user[5]. In Figure 2, all users are given primary rights.

In addition to the objective and the priority of using spectrum bands, this paper considers an additional attribute of spectrum, *usage mode*, systematically. Three usage modes are introduced; exclusive use, club use, and commons use[6]. Further, the paper proposes to consider usage mode in two levels: usage mode specified by the government (*Mode-G*) and usage mode specified by users, i.e., licensees (*Mode-L*).

In the exclusive use, there is only one spectrum user who is allowed to use a band/block exclusively. For the club use, there are two or more users of the same spectrum band/block; the way in which the users are admitted and requested to coordinate is specified by the government for Mode-G or by the licensee for Mode-L. The commons mode, as the naming indicates, is an open and free use by unspecified users as in the case of a city park or streets used by many people. We consider usage mode more in detail in subsection II. E.

In addition to the specifications at the ALLOC level as explained above, there are many technical regulations including power emission, prevention of interferences, protection from interferences, data transmission method, standardization, etc. This paper, as stated in Section I, takes such technical regulations as given. Section IV will propose a system in which decisions on ALLOC made by direct command and control by the government (and ITU) be replaced by decisions by the government simulating the functioning of market mechanism.

D. Assignment of spectrum blocks (licensing)

The second stage of specifying spectrum utilization, ASSGN, first divides each spectrum band into one or more spectrum *blocks*. The block is the actual unit of spectrum to be assigned to users. To each user is issued a license. In the present-day system of spectrum utilization in Japan, the licensee is selected by the government on the first-come basis or by discretion, and recently by comparative hearings. In U.S., U.K., and other countries, as known

5 The right on the secondary basis, roughly speaking, corresponds to “easement” discussed in Faulhaber and Farber [2002].

6 The term “club” was used by Sugaya and Yuguch [2002].

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widely, attempts have been made to select initial licensees by auction.[7] In the proposal of this paper, licenses are to be issued solely on the outcome of lease auction.

In Figure 2, we see that band A is divided into two blocks with licenses A1 and A2. Band B is divided into three blocks, B1, B2, and B3. Further, band C is not divided and bands D and E, being unlicensed ones, have no licensee.

Each license has its duration indicating the date it becomes effective and the date it is terminated. In Figure 2, each of the two broadcast licenses in band A has a duration of 10 years, whereas each of the three blocks of band B for commercial mobile services and license C have a duration of 5 years.

In the present-day system in Japan and in other countries, the duration of a license is established formally by law, but its actual effect is unclear, since in most cases a license is renewed repeatedly. As a consequence, a license is often considered to represent a semi-permanent right of using the spectrum block free of charge. This did not bring in problems at the time that the supply of spectrum was abundant and its effective price was zero. However, once the supply became tight and the effective price no longer zero, such semi-automatic renewal of a license gave its holder an economic advantage and vested interests.

Attempts to relocate spectrum from low-efficiency use to high-efficiency one have been made under the governmental command and control in Japan and in other countries. Outcome from such attempts, however, is limited and is far from solving the problem of the extreme inefficiency in spectrum utilization, because of oppositions by incumbent license holders.

In the system to be proposed in this paper, the duration of a license is to be observed strictly. The holder of a license must win an auction in order to continue to use beyond the termination of a license for the same block of spectrum that the holder used previously.

E. Usage mode

In this subsection, we consider spectrum utilization at the present time with regard to Mode-G and Mode-L. The row of Mode-G in Figure 2 shows that bands A through C are of exclusive mode and bands D and E of commons mode.

The exclusive mode of spectrum utilization is typical in the current system. The club

7 See, e.g., Kwerel and Rosston [2000] for U.S. and Cave [2002] for U.K.

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mode is also seen with many spectrum bands such as those for microwave communication. The spectrum band for commons use in the present-day system is known under the name of "unlicensed band." It is an open and free use without a license, hence the word "unlicensed".

The choice at the level of Mode G, especially the choice between the exclusive mode (combined with a property system) and the commons mode, has been in the center of debates on the use of spectrum. We note that there are strong advocates for introducing the commons use widely, emphasizing the benefits of technological progress such as UWB, overlay, and SDR.[8] As such, it is a demand to change ALLOC specifications, and, under the present-day system, the only way to meet such demand is through the governmental command and control. We point out, however, that it is possible to accommodate commons use in Mode-L under MLA, i.e., to realize commons as a choice of spectrum users. We also point out that it is possible to accommodate commons use in Mode-G under MLA with certain arrangements on public budgeting to supply commons as a public good (see section IV.D).[9] This paper attempts to introduce a system in which the demand for spectrum for commons may be realized under market principle, not through direct command and control by the government.[10]

To explain further, observe that usage mode specified by licensees (Mode-L), as shown in Figure 2, simply reflects the fact that the licensee of exclusive use in Mode-G may introduce club or commons mode to final users of the spectrum. Users in band A, broadcast stations, provides consumers with broadcast services in commons mode (free-to-air broadcast) or in club mode (pay per station or pay per view). Band B is used by mobile-phone operators, who provide their subscribers with mobile-phone services in the club mode. The licensee of block C, e.g., a fire station, has an exclusive right to use it (exclusive use in Mode-G); we state, just for a formality, that the fire station provides the service produced with spectrum C to itself exclusively (exclusive use in Mode-L). Band D is an example in which Internet access providers and their customers are given by the government the right to use the band in commons

8 See, e.g., Gilder [1994], Baran [1995], Noam [1998], Benkler [1998] , and Ikeda [2002] among many others.

9 Fauhlhaber and Farber [2002] points out that a use in commons mode can be accommodated in the property system.

10 It would take more than ten years to implement the proposal of this paper to a full extent (see section V). The author of this paper, therefore, does not oppose to assigning some spectrum bands under the governmental command and control to urgent needs at the present time such as wireless Internet access.

mode (unlicensed use). Likewise, band E, an ISM band, is used freely by consumers (final users) without licenses. For these cases, there is no need to consider the duration of a license or a Mode-L specification.

Thus, it is seen that a spectrum block can be used in the club or the commons mode at the level of Mode-L as well as at the level of Mode-G. In addition, Mode-L club or commons may be introduced by an exclusive user at Mode-G. This paper proposes a system in which the choice of mode be made preferably at Mode-L, not at Mode-G, i.e., competitively under market principle.

III. Spectrum Relocation by means of Modified Lease Auction (MLA) ---Competitive Assignment of Spectrum Blocks

A. Outline

This section proposes *modified lease auction (MLA);* it is a means for both ASSGN and ALLOC. For the convenience of explanation, we will make a proposal on ASSGN in this section, and then on ALLOC in the following section.

First of all, observe that the present-day system under the governmental command and control is a zero-price lease with high probability of repeated renewals. The system to be proposed in this section, MLA, is under the control of market power (auctions); further, it is a lease with clearly stated duration. The difference of the two systems is quite large; the cost of "jumping" from the present-day system to MLA would be very high. We need a scheme for gradual transition, which will be presented later in section V. The system of MLA to be presented in this section, therefore, is a long-term target; it is one for the case in which systems of spectrum utilization were designed from scratch.

In the following subsection, III.B, the system of (simple) lease auction is explained together with its merits and shortcomings. Subsections III.C and D together will introduce modified lease auction (MLA), an improvement of simple lease auction with regard to the risk that the incumbent spectrum user (lessee) faces. In subsection III.E, we will compare MLA with other systems for spectrum utilization, including the property system, and conclude that MLA is a system with balanced properties.

B. The system of (simple) lease auction (LA)

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Let us first explain (simple) lease auction (*LA*) for spectrum assignment. It means the following. The ownership of radio spectrum is in the hand of the government, which leases a block of spectrum to a user by auction on the lease price. This paper proposes that, for a reason to be explained later in subsections V.C and D, the lease be applied to all users including private, public, and government users; there should be no exception to this principle. Further, once a user obtains a license for a particular block of spectrum through an auction, the licensee will be allowed to use it, sell it, or sublease it, within the ALLOC and the ASSGN specifications.

Typically, an assignment of a spectrum block with LA would proceed as follows. First, the government establishes terms of a license including its duration. Before the start of a license, an auction would be held on its lease price; the winner would obtain the license upon paying the bid price. When the termination of the license approaches, another auction would be held to determine who would obtain the license for the following term. And so on.

The obvious advantage of introducing lease (LA) in the assignment of spectrum lies in its *flexibility*. That is to say, in comparison with the command-and-control system or with the property system, LA makes it easy for a block of spectrum to be relocated from old to new users according to the need arising from technological and economic changes. This will increase the efficiency of spectrum utilization, and the society as a whole will be benefited from it. Further, the amount of money involved in LA (or MLA for this mater) would be far less than auctions for initial assignments or those in a property system as proposed in Faulhaber and Farber [2002] and Kwerel and Williams [2002]. Incentives for hoarding, speculations, and “winner’s curse” would be limited in LA and MLA.

There is a serious disadvantage, however, in the system of LA. From the standpoint of a spectrum user, it would be desirable to be able to use it in the future indefinitely, since such would protect investment of the user made in the past. In other words, LA would impose the spectrum user the risk that the license might not be renewable. We call it the risk of lease discontinuation (*ROD*).

Two categories of ROD may be distinguished. The first category of ROD (*ROD1*) arises when newcomers outbid incumbents in the auction to be held for the lease following the current one. It is always possible that, because of a change in technological or economic

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conditions, a new service or a new method for providing the same service as the incumbent did may emerge so that a newcomer can offer a higher price for leasing the spectrum than the incumbent can. Under the property system, the incumbent could continue to use it at least until the investment made in the past was fully recovered. Under the system of LA, the incumbent user might not be able to do this. This is ROD1.

The second category of ROD arises from an ALLOC decision by the government (to be explained in the following section). When the government decides to change the objective for the spectrum band that the incumbent has been using, the incumbent must give up using it beyond the expiation of the current license. This is *ROD2*.

It is possible that ROD1 and ROD2 bring excessive risk to the spectrum user; as a consequence, the investment made under such risk might be less than the level optimum to the society as a whole. We will discuss implications of risk more in detail later in subsection IV.E. In the following two subsections, we will propose modifications of LA so that the shortcomings arising from ROD1 and ROD2 may be remedied.

C. Protecting incumbents from ROD1

In order to protect incumbents from ROD1, we can employ one or more of the following modifications of LA:

(a) First of all, when a spectrum band is composed of more than one blocks, incumbents may be protected if the government holds a (lease) auction for all of the blocks in the band simultaneously and, at the same time, designates the object of the auction to be *some* block in the band, not a particular block. Let us explain by taking a case of mobile phones as an example.

Suppose that there are six blocks in the band for mobile phones. It is desirable, but not imperative, that the band be consecutive and each block be of the same size. Suppose further that an incumbent operator of mobile phones has been using the second block of the band. The (lease) auction for the six blocks is to be held simultaneously, and auction participants including the incumbents are to bid for a yet-to-be-designated block in the band. (If the size of the blocks differs, the bid price should be set for a unit of spectrum (such as 1 MHz) instead of for an entire block.) If the incumbent operator wins, i.e., finishes the auction within the top six bidders, then the operator will be entitled to lease the same block that the operator used

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previously. Thus, an incumbent operator would lose a license only when the incumbent cannot outbid the lowest wining bid for the six blocks of the band. Such an arrangement would reduce ROD1 greatly.

The following can be used regardless of the number of blocks in a band.

(b) To give a discount of the lease price to incumbents: this would protect incumbents by letting them save the amount of money to be paid for lease. In other words, newcomers would be able to access a spectrum block only if they could offer a significantly higher price than the incumbent did; the discount may be justified in view of the capital stock that the incumbent carried over from the past. To find an appropriate percentage of discount, trials and errors may be needed. To begin with, a discount of 50% for a 5-year lease and a discount of 30% for a 10-year lease might be suggested.

(c) To hold an auction for lease several years prior to the beginning of the lease period: this would favor incumbents against newcomers in terms of the timing of decision. Because of the investment made in the past, it is easier for incumbents to make a decision on the demand price for a license in the future than for newcomers starting from scratch. Further, this would lower the burden imposed on the incumbents in the maintenance of the carried-over capital stock and others, thus letting the incumbents bid higher than otherwise.

(d) To use what may be called a "pre-auction," in which the winner obtains a discount of lease price in exchange for the amount bid. A pre-auction might be held on the percentage of discount or on the amount of discount; it is like auctioning on a "reservation fee" for a theater ticket, or more precisely, like auctioning on a "fee for partial reservation." This, in effect, is a combination of (b) and (c) above, since this would protect incumbents in terms of both the amount of money to be paid for lease and the timing of decision.

(e) To create futures and/or options markets for the right of leasing spectrum. This is an extension of (d) above. Auction for a lease would be held some periods before the actual lease starts, say, 10 or 15 years prior to the start of a 5-year lease. Then, futures and/or options markets for the lease might develop, and incumbents might be able to purchase the right to continue to use in the future the same spectrum block that the one used previously.

We can think of other ways for protecting incumbents from excessive ROD1. This may be a possible research subject in the future. We will discuss on why incumbents need to

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be protected at all later in subsection E.

D. Protecting incumbents from ROD2

The second category of the risk of lease discontinuation, ROD2, arises from the government decision to change the objective for using spectrum. As stated in the following section, the government changes ALLOC in such a way that, roughly speaking, the size of spectrum bands with low lease prices be decreased and the size of spectrum bands with high prices be increased. In order to do this, the government must terminate the specification of the objective of a (low-priced) spectrum band. This means that there would be no auction in the future for the spectrum band with the terminated objective. A new objective would be established and initial licenses for the band would be assigned on new auctions.

Therefore, the old user of the spectrum with the objective to be terminated must give up using it at the end of the current lease, even if the user could bid sufficiently high to win an auction over competitors under the old objective. In other words, ROD2 is a risk arising not from the insufficient competition capability of the user, but from the insufficient competition capability of a group of users with the old objective.

We propose to create a *spectrum insurance* to protect the user from ROD2. The decision by the government to discontinue an ALLOC specification may be justified from the standpoint of the demand and the supply of all spectrum resources. However, to an individual user, it is like a natural disaster or a fire for which the user has no direct responsibility. Insurance is the best way to deal with such risk.

Under the spectrum insurance proposed here, a spectrum user would declare the amount to be compensated in case such a discontinuation of the lease took place. This amount might reflect the part of the investment having been made for using the spectrum and not having been recovered through depreciation allowances and other means. Roughly speaking, the amount insured would be determined by the spectrum user in such a way that the outcome to the user in the case of lease discontinuation be indifferent to the outcome from the case of no discontinuation.

The user should pay an *insurance fee* for this, since, without an insurance fee, there would be a strong incentive for a licensee to declare an extremely high amount to be compensated in case of lease termination arising from a change in ALLOC specifications. It is

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proposed that the amount of insurance fee be equal to the product of an *insurance-fee rate* and the amount of money insured. It is further proposed that this spectrum insurance program be run by the government as an actuarially fair insurance; that is to say, the insurance-fee rate should be determined so as to balance the fee revenues and the payments of insurance money in the long run. Further, the government should choose spectrum bands to be reclaimed so as to minimize the sum of insurance payments.

We will discuss the behavior of the user with regard to spectrum insurance together with its implications on the relocation of spectrum later in subsection IV.D.

E. Economic meanings of ROD and comparison of MLA with other systems

Let us consider here economic meanings of ROD. We also compare in this subsection MLA with other systems for managing spectrum resources, including the governmental command and control and a property system.[11]

First of all, ROD arises when the spectrum user is forced to give up using a spectrum block because of a decision made by other spectrum users (ROD1) or by the government (ROD2). It is observed that the presence of ROD is a consequence of economic growth and changes with new spectrum users; there would be no ROD if the whole economy remained stationary (stagnant) so that the economic activities each year were the same as the economic activities in the preceding years. Thus, ROD is a price which incumbent spectrum users have to bear in order for the whole economy to achieve flexibility in spectrum utilization.

Thus, we can state that the degree of ROD determines the balance between the security to incumbents and the flexibility for entry by newcomers; we face a tradeoff between security and flexibility in using spectrum. Figure 3 illustrates this tradeoff. To choose a system for spectrum utilization is to choose a point on a curve representing the tradeoff.

We first observe that the level of ROD is near zero but the flexibility is nil in the current system (command and control with automatic renewal by the government), which is represented by the origin O in Figure 3. In the property system, ROD is low but not zero, and the flexibility is higher; it is represented by point A on the trade off. In (simple) LA, the flexibility

[11] Note that this paper considers “spectrum commons” as a mode of using spectrum which can be realized under command and control, under a property system, or under MLA (subsection II.E). Thus, this paper proposes MLA as an alternative to command and control or a property system, not an alternative to commons.

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is high, but the level of ROD is also high, since incumbents are not protected at all; LA is represented by point C. We can conclude that MLA provides us with a medium level of both ROD and the flexibility; given a preference over ROD and flexibility, a point such as B in Figure 3 may represent an optimum.[12] An important question is which point between A and C on the tradeoff is to be chosen. The following section, section IV, gives a partial answer to this, but the present author agrees that it is for future research to establish a solid theory on this issue. Meanwhile, in the reality, actual choice may be made by the government through successive adjustments, i.e., by trials and errors. ****** Insert Figure 3 here. ******

The remainder of this subsection is devoted to comparing the property system (to be abbreviated as *PS* in this subsection only) and MLA with regard to flexibility and security.

On the one hand, it is clear that the security of PS is greater than that of MLA (i.e., ROD is higher with MLA than with PS), since, in PS, the user of spectrum is its owner and can always make a decision whether to continue using it or not.

On the other hand, the flexibility of MLA, in general, is greater than that of PS, since the chance for newcomers to be able to lease spectrum is greater with MLA than PS. In this regard, it is sometimes stated that, under an ideal condition, the flexibility of PS may be as great as that of MLA. This is correct, but, in the reality the market mechanism is far from being complete and this assertion does not hold.

In the Arrow-Debreu world in which complete contingency markets existed, a high flexibility might be achieved at a Nash equilibrium of PS. In reality, of course, the transactions cost of having such complete markets is prohibitively high; we have to live with a system of incomplete markets and to simplify a large number of contingencies into the reality of decision making under uncertainty.

There are at least two sources which lowers the flexibility of PS. One is the presence of economies of scale in the use of radio spectrum. Spectrum resources, as other space resources (see subsection II.A), exhibit economic of scale in the sense that, if more than one spectrum bands or blocks were put together and placed under an integrated use, the outcome from the integrated spectrum would be higher than the sum of the outcomes from the spectrum

[12] Observe that the property system is a special case of LA in which the duration of a license is infinitely long; the position of LA (and of MLA for this matter) on the curve of Figure 3 also depends on the length of its duration.

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used separately. For the case of radio spectrum, an example of positive externalities may be the case of CDMA for distributed transmission of signals. Further, one can simply recall that the spectrum blocks for TV channels are put together in a small number of bands so as to save the cost of manufacturing TV devices.

Note that the range of spectrum bands or blocks which exhibit significant scale economies depends on the technology for using them; hence, the range may vary (usually it expands) depending on technological progress. If the range is expanded significantly, then it may become advantageous to integrate some number of spectrum bands or blocks into one.

Now, under PS, when such an integration is attempted through spectrum trade, it is possible that the owner of a small piece of spectrum who happened to be located at a strategic position charges excessively high price for it, as we see in the case of land from time to time (the case of hold-up). Relocation of spectrum would be obstructed, then. The consequence, as experiences show, is that the cost of reaching even near to a Nash equilibrium in a hold-up case is high in time and money; the parties, after long and wasteful negotiations, would be forced to settle at a contract which is far from optimum. Thus, the flexibility of PS is lower than that of MLA, in which any hold-up would be eliminated at the time of auction. [13]

The other source which lowers the flexibility of PS is the presence of capital stock and other investment for using spectrum. The cost of relocation to the user (i.e., the least amount of money that the user would accept for giving up using a spectrum block) depends upon the size and the contents of investment made in the past on capital stock (devices, equipment, etc.) and others for the use of spectrum. To realize a relocation of spectrum desirable to the whole society, this cost must be revealed in some way. In PS, the only way to reveal it is through the course of negotiations; the transactions cost (i.e., the negotiation cost) for this would be high. In MLA, as explained in subsections IV.C and D, each user’s relocation cost is readily revealed through spectrum insurance. Thus, we can assert that the flexibility of PS is lower than that of MLA.

13 There is a case in which it is possible to bring the benefit of positive externalities even in the presence of spectrum hold-up; it is the case in which the user can bypass held-up spectrum by means of new technology such as software-defined radio (SDR) at a cost far lower than the cost of realizing the intended integration. Therefore, once SDR becomes not only an engineering goal but also economic reality, the harm from hold-up may be avoided.

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IV. Relocation of spectrum bands by the Government under Market Principle

A. Outline

In the preceding section, we proposed MLA as a means for assigning spectrum blocks competitively. This will increase the flexibility of spectrum usage within given ALLOC specifications. This section is devoted to proposing a relocation system with regard to spectrum bands, i.e., ALLOC specifications themselves.

The following subsection, IV.B, will be devoted to proposing a scheme for the government to relocate spectrum between different bands not by direct command and control as it does today, but by simulating the functioning of competitive markets. Lease prices obtained through MLA for assigning spectrum blocks and the amount declared by spectrum users for insuring against ROD2 will be used for this. Subsection IV.C examines implications of the proposal given in IV.B. Finally, in subsection IV.D, we summarize the system proposed in this paper and explain how to accommodate spectrum commons into MLA by treating it as a public good.

B. Relocation of spectrum bands by the government simulating competitive markets

This paper proposes that the government conduct relocation of spectrum bands by revising the ALLOC specifications. The government should relocate a band from inefficient use (with a low lease price) to efficient use (with a high lease price), taking into account the cost of terminating the use of the inefficient band, which is revealed by its users as the amount to be compensated for termination. Thus, the government should compare, for each band, (a) the estimated increase in the present value of the total lease fees to be collected on the reclaimed band in the future, and (b) the amount of total insurance payments for reclaiming the band. Let r_{old} be the annual lease fee of a band in question and r_{new} be the expected annual lease fee of the band when allocated to a new objective. Let C be the amount of insurance money to be paid to the users of the band when it is reclaimed. Then, the government should relocate the band to the new objective, whenever the present value of ($r_{new} - r_{old}$) exceeds C, i.e.,

$$(r_{new} - r_{old}) / i > C,$$

where i denotes the expected rate of interest in the future and the left-hand side of the inequality, the present value, is calculated as perpetuity. This means that the government should make a decision on the ALLOC specifications so as to maximize the present value of the net annual

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revenues from leasing and relocating its spectrum resources. Thus, the government simulates the working of competitive markets on the allocation of spectrum for achieving an optimum outcome.[14]

Needless to say, what is stated above is a simplified description of the behavior of the government. In the reality, the government would face many problems. One problem may be the choice of a "speed" of relocation. Another may be the actual choice of bands for relocation, which will likely involve combinatorial choices in a large and complex domain because of the presence of economies of scale and externalities.[15] Further details on these points are for research in the future.

C. The behavior of spectrum users and its implications on the relocation of spectrum bands

An assumption in the discussion of the preceding subsection is that the amount of money declared by a user of spectrum for insurance reveals the "true" cost that the user incurs when relocation takes place. We examine this assumption in this subsection, and then state implications of the behavior of the users and that of the government.

We start by considering a simple case. Suppose first that all users of spectrum are risk-averse. Suppose further that the government provides the spectrum insurance actuarially fair so that the insurance-fee rate, say s, is equal to the probability of relocation to each user, say p:

$$p = s.$$

Then, a typical user would choose the amount of money to be insured, C, so that the insurance be complete; i.e., the net income in the event of relocation (i.e., lease discountinuation) be equal to the net income in the event of no relocation:

$$C - D + R_D / i - sC = R_N / i - sC,$$

i.e.,

14 It is known, in welfare economics, that an efficient allocation of resources is achieved when the supplier of the resources maximizes its revenue, taking the resource prices as given (see, e.g., Mas-Corell et al [1995], ch.10). For the present case, observe that the government is the sole supplier of the spectrum resources and makes decisions on the allocation of spectrum bands taking prices (lease price and insurance money) as given.

15 Observe that, the system proposed in this paper would let the data needed for global-scale relocations of spectrum be revealed by the users as lease prices and insurance amounts. The property system does not provide this, and would have to operate on incompletely revealed information.

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$$C = D + (R_N - R_D) / i,$$

where D denotes the once-hand-for-all net expenditure to be made at the event of relocation to continue the user's business, R_D the expected annual net income after relocation, and R_N the annual net income for no relocation (see, e.g., Mas-Colell et al [1995], ch.6, Ex. 6.C.1). It is evident that, for this case, the user reveals the true cost of relocation as the insurance amount, C: the scheme for relocation proposed in the preceding section would work.

In general, without the simplifying assumptions stated above, it is possible for the outcome from the proposed system to be distorted away from optimum and also to introduce an unjustifiable redistribution of income among the users. This is true regardless whether or not all users are risk averse.

For example, if a user can confidently forecast that the probability for the user's band to be reclaimed by the government is high, it is possible for this user to declare an extremely high amount for insurance to crop a windfall income.

The best way for the government to avoid such an undesirable outcome is (a) to disclose all the data on auction prices and insurance amounts to the public, and (b) to allow the users to revise their insurance amounts as many time as they choose. Then any attempt to exploit a chance for windfall income by declaring high insurance money would be undercut; other users would declare insurance money lower than the one declared for windfall benefits. With ample time given for such adjustments, the chance of windfall benefits would be eliminated; every user would eventually declare honestly.

To summarize, in the proposed system,

1. The value of each spectrum block for current and alternative uses are provided by auction as lease prices;
2. The cost of relocating a spectrum band is revealed by the incumbent as insurance money (honestly in the long run);
3. The government relocates spectrum bands so as to increase the efficiency of their use;
4. The government determines the fee-rate for spectrum insurance so as to balance the budget for spectrum insurance (i.e., to provide actuarially fair insurance); and
5. Thus, the users of spectrum bear the cost of the spectrum relocation in the form of paying insurance fees.

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D. Provision for spectrum commons as a public good

We have observed that a lease auction system, LA or MLA, can accommodate various usage modes both in Mode-G and in Mode-L. We take full advantage of this in the system proposed in this paper. In general, it is desirable to "privatize" the use (not the ownership) of spectrum resources whenever possible. In order to realize a club or commons mode, the first choice should be Mode-L, not Mode-G. Further, we propose that Mode-G club and commons be realized as public goods, as explained below.

First, we propose that a public agent be established as the "user (licensee)" of a block for a Mode-G commons. The objective of this agent is to secure a spectrum block at a lowest possible cost for the use by the public in the same way that unlicensed band is used today. In order to bid for this under MLA, the agent is given a certain amount of budget by the government administering the general public budget (e.g., Ministry of Treasury, to be denoted as *GPB* in this subsection only). The size of this budget should be equal to the greatest amount of money that GPB would approve in view of the "utility" of securing the block for the public. Thus, the service provided by this block is a public good to be supplied by the agent free of charge to final users (consumers)

This may seem a redundant way to secure a spectrum block as Mode-G commons for the reason that the public agent for commons could bid arbitrarily high as long as a budget is provided by GPB, the receiver of the auction income. Observe, however, that, in the proposed system, GPB should give a budget to the public agent in such an amount as to represent the demand price of the block to the society. It is possible for GPB to give "an unlimited budget" to the agent on its decision that the spectrum block "must be secured at any cost (e.g., for security)." Such a case should be an exception, though. Further, after an auction, the agent would end up with a (finite) price for leasing the block.

The following are some of the advantages of providing Mode-G commons as a public good, through auction, as explained above, instead of providing by the governmental command and control. Observe that this arrangement makes explicit the opportunity cost of securing a Mode-G commons. Thus, when a new technology fitting to a new Mode-G commons emerges and obtains a support by the public, it is possible to secure a spectrum block for it by having GPB allocate some budget for this purpose. Conversely, when the usefulness of a

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commons decreases (e.g., by a new technology superseding it), GPB can make an adjustment by trimming the public budget given to it. Of course, there would be a political or other process to change a public budget for such a purpose, and conflicts of interests, if any, would have to be solved. This arrangement, however, is better than the direct command and control process, since the latter generates direct confrontation among new and incumbent users, whereas the former can solve the issue in the framework of the allocation of the public budget.

The foregoing discussion suggests that, whenever possible, spectrum commons (and clubs) are better realized in Mode-L than in Mode-G. The reason is simply that Mode-L commons can be realized without a political process on the public budget. An example of this may be a group of manufacturers producing devices on new technology for communication services (such as a broadband Internet access) using a block of spectrum; the group may win an auction and pay the bid price from the revenue of selling the new devices; the block may be used in Mode-L commons or in Mode-L club as chosen by the manufacturers.

To summarize, this paper proposes that spectrum utilization under MLA be as follows. Club or commons use in Mode-G can be realized by the government, if desired, through a public-good provision as stated above. Alternatively and preferably, club or commons use can be realized in Mode-L through a (private) arrangement made by a user of an exclusive block. Thus, this paper proposes to let users of spectrum blocks choose a mode of use freely by considering the technology and the demand-supply conditions. Users, including public agents responsible for Mode-G club or commons, would be in competition each other. This would be beneficial to the consumers (final users of spectrum).

To facilitate our understanding, we will explain, in terms of Figure 4, an example of spectrum usage with the system proposed in this paper. Figure 4 is an extension of Figure 1; the items new or changed from Figure 1 are denoted by italics in Figure 4.

Let us first consider an example of government-arranged club use, the primary use of band C in Figure 4. In this case, the primary right would be won through auction by a public agent, and then given to public users such as police, coast guards, fire stations, and others in Mode-L club. If such a band is very important and must be secured for the security agents, then a very high amount of budget should be given by GPB to the agent.

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With regard to commons use, note that there are two types. Type-1 commons is like the unlicensed one at the present time. It is for the use within a small area such as household; examples are wireless telephones, home wireless LAN, and electric ovens. In Figure 4, band E is designated for type-1 commons use; the objective of this band is unspecified and license E is to be won by a public agent responsible for this block, which let the public use it free of charge (within the ALLOC and the ASSGN specifications). In the future, if an expansion of this block becomes necessary, this agent would be given an additional budget to win an auction for additional blocks. Further, if the price (lease fee) of this block increases, then the government may consider increasing the size of Band E though some relocation.

Examples of type-2 commons are what is called UWB (Ultra Wide Band) and overlay. They are for a secondary right to exploit the vacant portion of a spectrum band both timewise and areawise, thanks to newly developed technology. UWB utilizes a widely spread frequencies so as not to interfere the primary use in any band. Overlay uses software-defined radio (SDR); the device for SDR can detect unused segments of spectrum (with regard to frequencies, location, and time) and exploit them so as not to interfere the primary use of the same band.

In Figure 4, the secondary right to use band B is obtained by a public agent through auction; the secondary right would then be released for UWB. The lease price for this is to be paid by GPB so that, in effect, the UWB service becomes a public good.

Further, in Figure 4, band D is designated to be used for Internet access and the license D is obtained exclusively by a union of Internet access providers. The union uses this block as a Mode-L commons of type-2. In this case, the government may impose a regulation so that union membership be open and the members of the union share the payment of the lease price and the insurance fees according to a predetermined scheme. In effect, such a union would become a half-public, half-private entity.

The secondary use of band C in Figure 4 is specified to be Mode-G exclusive. In this example, too, the union of Internet access providers possesses an exclusive license CC; the block is also devoted to Internet access services. Since license CC is of the secondary right in this example, the block might be preoccupied by public security users from time to time. In that case, of course, the secondary rights to use band C must be conceded to the primary users;

to Internet users, such a case would appear that the internet were busy because of an emergency.

At this point, let us summarize the system of spectrum management as proposed in this paper. The following are the basic principles of the system:

1. The government is the sole owner of the spectrum resources.
2. Spectrum blocks are assigned (and reassigned) competitively under MLA.
3. Spectrum bands are allocated (and relocated) by the government simulating a competitive market; the government makes decisions for this by relying on a set of market-like rules and on the data (lease prices and insurance amounts) obtained from MLA. The government may rely on technical and other data on the secondary basis.
4. Mode-G commons are treated as a public good and will be run by a public agent with a given (public) budget for its lease and insurance fees.

V. Gradual Transition from the Current System to the Long-run Target, MLA

A. Outline

In this section, we deal with the issue of transition from the current system to the long-run target, which is MLA. As discussed in the preceding sections, MLA has a number of desirable characteristics over the current system (command and control by the government). The difference between the two systems, however, is so large that it is extremely costly to jump from the current system to MLA. The spectrum users under the current system, with the expectation that free use of spectrum would continue, have made a large amount of investment in the form of equipment and devices, human skills, business organizations, etc., which could not be recovered within a short period of time. We cannot simply discard such sunk investment by jumping to a new system. What is needed is a gradual, as distinct from sudden and once-and-for-all, transition, in which the current users of spectrum can make adjustments over years by using depreciation allowances and other means.

We note that all users of spectrum would be affected by the ASSGN stage of MLA, which would impose spectrum fees uniformly, whereas only a small number of users would be affected by relocation in the ALLOC stage and those affected would be protected by spectrum insurance. For this reason, the proposal in this section is directed mainly to the ASSGN stage of MLA.

Next, in addition to the above, we emphasize the need for informed transition. The number of spectrum users, even excluding those of mobile phones, is of the scale of 100,000 in Japan. In order to minimize the cost of transition, every user should be informed fully of the process of transition so as to be able to plan well ahead of the adjustments needed. This means that the government should spell out in detail the process of transition, including plans for major contingencies.

The transition process proposed in this paper is composed of three elements: (a) the formation of benchmark lease prices (BLP) during the preparation period, (b) the gradual implementation of spectrum usage fees during the execution period, and (c) a provision for income compensation.

To propose a process for transition, let us first define three periods; *the preparation period, the execution period,* and *the income compensation period*. Let in *M*, *N*, and *T* be the length of the preparation, the execution, and the income compensation periods, respectively. Furthermore, let the beginning of the preparation period be set at the beginning of the entire transition process, and let the beginning of the execution and the income compensation periods be set at the end of the preparation period. Figure 5 illustrates this arrangement for the case of $M=5$, $N=10$, and $T=20$ (years). In the following, we spell out the proposed activities for each of these three periods. ****** Insert Figure 5 here. ******

B. Formation of benchmark lease prices (BLP) during the preparation period

The main objective during the M-year preparation period is to form *benchmark lease prices (BLP)*. BLP will be used as a proxy for market lease prices during the execution and the income compensation periods.

In order to do this, the government would first define the spectrum blocks by specifying a range of frequencies and a geographical area with, if necessary, a time of use and a priority. Figure 6 gives an illustration with a simple case in which the frequencies and the areas are represented by a vertical axis and a horizontal axis, respectively. In Figure 6, spectrum band D may be a broadcast band or an unlicensed band; there is no geographical division for that band. Further, bands A through C are not divided in area III.

Gradual formation of BLP would proceed as follows. During the preparation period,

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any new assignment of spectrum blocks must be done by auction (MLA). It would not be difficult to do this, since the auction would be held for new assignments and no incumbent user would be involved. Suppose in Figure 6, the gray rectangles were assigned by auctions, and white rectangles were used by incumbents. The BLP for each rectangle would be determined in the following way. First, for the gray rectangle, the BLP would simply be the price determined by auction. Second, for the white rectangle, the BLP would be the value obtained by linear interpolation of the prices with the gray rectangle nearest to it. If two or more linear interpolations existed, the average would be taken. If no interpolation were available, simply apply an extrapolation. Those rectangles of extremely low frequencies or of extremely high frequencies, or those rectangles located in an area in which the supply of spectrum clearly exceeded the demand, the BLP would simply be set to zero. Further, BLP should be revised regularly, say, monthly or quarterly.

Whereas this process, at the outset, might not be so accurate as desired, we would obtain at least a first approximation of BLP. As time goes on during the preparation period through the execution period, the number of gray rectangles would be increased so that the BLP would be closer to market prices.

During the preparation period and thereafter, new users of spectrum would be under MLA to its full extent; thus, they would pay lease fees as determined by auction and are subject to relocation with the protection of spectrum insurance. The incumbents, however, would be outside of MLA and pay nothing except that they would be informed of the BLP of the spectrum blocks they were using. However, there seems to be no reason to exclude them from subscribing to the spectrum insurance by accepting the possibility of ALLOC relocation on a voluntary basis. It may be expected that those blocks with very low efficiency would be relocated; reclaimed bands should be put to auction for newcomers, increasing the number of gray rectangles in Figure 6.

Finally, by the end of the preparation period, for each block used in Mode-G club or commons, a public agent should be established as explained in section IV.

C. Gradual increase in lease fees during the execution period

The execution period is a period in which the incumbents would start paying *partial* *lease prices (PLP)* as follows. The PLP in the n-th year of the execution period would be equal to *n/N* times the BLP of the block being used:

$$PLP(n) = (n/N)^* BLP(n), \quad n=1,2,\ldots,N.$$

Thus if *N=10*, PLP would start from zero, and would then increase by 10 percent annually; in the 10th year, i.e., at the end of the execution period, the PLP would be equal to BLP, *the full lease price (FLP)*.

The status of incumbents during the execution period would be the same as in the preparation period except that (a) they should pay PLP, and (b) they should be allowed to "return" to the government a potion of the spectrum they were using in order to avoid payment of PLP. (But this is not relocation; the incumbents returning spectrum cannot claim insurance payment in the case they subscribe to it.)

Thus, the incumbents could adjust their use of spectrum gradually during the execution period. They might return to the government a portion of the spectrum blocks they were using; in this case, they might employ more efficient equipment to save the spectrum need or they might shift to other means for communication such as optical fibers.

At the end of the execution period, the incumbents would start paying FLP. Thus, it would be straightforward to move to a full-scale MLA at the end of the execution period. In particular, all licenses would have to be issued under MLA upon expiration, and the incumbents as well as newcomers would face ROD with the spectrum insurance. Furthermore, once the execution period is over, the users of spectrum should be allowed to sell or sublease licenses as desired but within the ALLOC and the ASSIGN specifications.

D. Income compensation

An obvious difficulty in an attempt to implement MLA with the transition process as proposed above would be political opposition by incumbents. They have been using spectrum for years free of charge, and now they would be asked to pay PLP and eventually FLP; it is natural for incumbents to oppose strongly to the introduction of MLA. This is, after all, an issue of income distribution between the incumbent spectrum users and the rest of the society. In case spectrum is used by a branch of the government (e.g., by the Ministry of Defense), the issue is essentially of the allocation of public budgets to that branch. When spectrum is used

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for security or safety purpose, opposition to MLA would be strong and might sound justifiable.

In this section, we propose a scheme for income compensation for incumbents; this scheme might be used in order to make an implementation of MLA and the transition plan easy to be accepted by incumbent users, particularly by government users. The scheme for income compensation would change the distribution of income, to an extent chosen, in favor of the incumbents at the burden on the rest of the society. However, it would not affect the incentives for the incumbents to save spectrum at all. Thus, the scheme is independent of the non-distributive effects of MLA with the transition process as proposed previously[16].

Let us begin with reminding of the definition of the compensation period; Figure 5 shows an example of a period starting at the end of the preparation period and continuing for 20 years. During the compensation period, incumbent users might receive compensations, whereas once the income compensation period is over, there would be no compensation at all. This is a sunset scheme.

In order to specify an amount of money to be returned to an incumbent for compensation, let us define *the base amount of payment* in period t, $BAP(t)$, to be the value of the spectrum *held by the incumbent at t=0* evaluated in terms of PLP or FLP, whichever is prevailing, in period t. Observe that $BAP(t)$ would vary over time depending on PLP or FLP, but the spectrum base used for calculating $BAP(t)$ would not change over time.

Next, we introduce *the degree of compensation* for period t to be $d(t)$ in such a way that

$$0 \leqq d(t) \leqq 1 \text{ for } 0 \leqq t \leqq T; \quad d(t) = 0 \text{ for } t > T.$$

An example of $d(t)$ is a linear sunset:

$$d(t)=(T- t)/T, \text{ for } t \leqq T, \text{ and } d(t)=0, \text{ for } t > T.$$

Other examples are conceivable.

Further, we define g ($0 \leqq g \leqq 1$) to denote *the ratio of compensation*, which may differ depending on the group to which the incumbent belongs. For example, in a simple setting, we might set a near-full compensation for military and security users ($g=1$), partial compensation for government users, public utilities, public transportation operators, welfare

16 The effects of the scheme for income compensation proposed here are similar to those of a scheme for levying a charge on public (e.g., military) users of spectrum and at the same time letting them to sell or lease spectrum, as proposed by Cave [2002].

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agents, etc. (*g=0.5*), no compensation for profit-seeking entities and individual users (*g=0*).

The *actual amount of compensation* in period *t*, *AAC(t)*, may be set by

$$AAC(t) = g*d(t)*BAP(t), \qquad t = 1,2,\ldots,T.$$

Note that

$$0 \leqq AAC(t) \leqq BAP(t), \text{ for all } t,$$

so that the actual amount of compensation is always within *BAP(t)* and the government's budget for income compensation will never be in deficits.

The actual amount of compensation, *AAC(t)*, would vary as *BAP(t)*; it would typically decrease as time goes on. If the incumbent continued to use the spectrum blocks which were held at the beginning of the income compensation period, then the net payment by the incumbent would be *BAP(t)* minus *AAC(t)*. If *d(t)=1* and *g=1*, the incumbent would be fully compensated; the spectrum blocks would be used free of charge. If not, the incumbent would be compensated partially.

Observe that if, in the middle of the income compensation period, the incumbent returned a portion of the spectrum which was held in the beginning of the period, then the incumbent would not need to pay PLP or FLP for the returned spectrum, i.e., the incumbent would be paying less than *BAP(t)*, but would still continue to receive *AAC(t)*. In other words, by returning the spectrum, the incumbent would be excused of paying the lease fees for it *without losing the compensation.* It is possible that the incumbent receives a net positive amount (i.e., a subsidy) from the government. But note that the government would never be in deficit even with such compensation, since *BAP(t)* is calculated on *BLP(t)*, which, in this case, would be fully paid by a newcomer winning the auction on the returned spectrum. Thus, this scheme would provide a strong incentive for the incumbent to save and return spectrum, which would be beneficial to the society as a whole (a win-win case). In other words, the income compensation scheme as proposed here is independent of the non-income effects of MLA in the transition process.

To conclude, the overall effects of the transition process with regard to lease prices would be something like the following. In the beginning of the transition period, the average lease price (PLP or FLP) might stay at a high level because of the scarcity of the spectrum created with inefficient use. Newcomers might bid aggressively to obtain the right to use a spectrum block, since the spectrum would likely promise high returns from the service production using it. However, as time goes on, incumbents would start returning spectrum to the government; the returned spectrum would be assigned to newcomers by auction, increasing the supply. Thus, the average lease price would gradually fall. At the end of the execution period, it is possible that relocation of spectrum would proceed significantly to lower the average lease price of the spectrum significantly so that the spectrum might be close to a free good once again, if only temporarily.[17] Such process may be accelerated if the government arranges incentives for incumbents to return spectrum. An example would be to give discounts of PLP to incumbents releasing spectrum voluntarily during the preparation and the execution periods.

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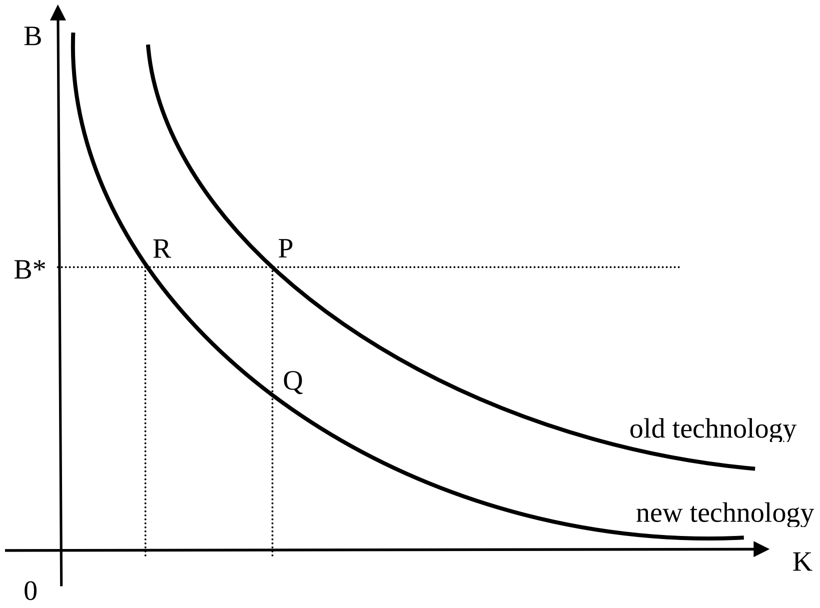
Figure 1: Tradeoff between capital stock (K) and spectrum bandwidth (B) in the use of spectrum with given technology



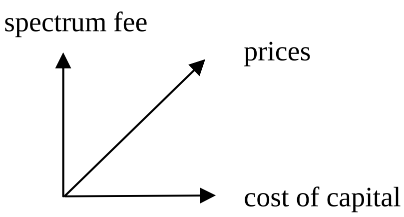


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Figure 2: Example of Spectrum Usage (Current System)

ALLOC	Spectrum Band (Frequencies)	Band A		Band B			Band C	Band D	Band E
	Objective	Broadcast		Commercial Mobile			Security	Internet Access	Unspecified (ISM)
	Priority	Primary		Primary			Primary	Primary	Primary
	Usage mode specified by government (Mode-G)	Exclusive		Exclusive			Exclusive	Commons (“unlicensed”)	Commons (“unlicensed”)
ASSGN	Spectrum Block (Area, Time)	A1	A2	B1	B2	B3	C	(D)	(E)
	Duration	10yrs		5yrs			5yrs	(indefinite)	(indefinite)
	Spectrum User (Licensee)	Broadcast Stations		Mobile-phone Providers			Police, Fire Stations	(NA)	(NA)
	Usage mode specified by user (Mode-L)	Club/ commons		Club			Exclusive	(NA)	(NA)
Final user		Consumers, etc., of Services using Spectrum							

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Figure 3: Tradeoff between Security (ROD) and Flexibility in Alternative system for Using Spectrum

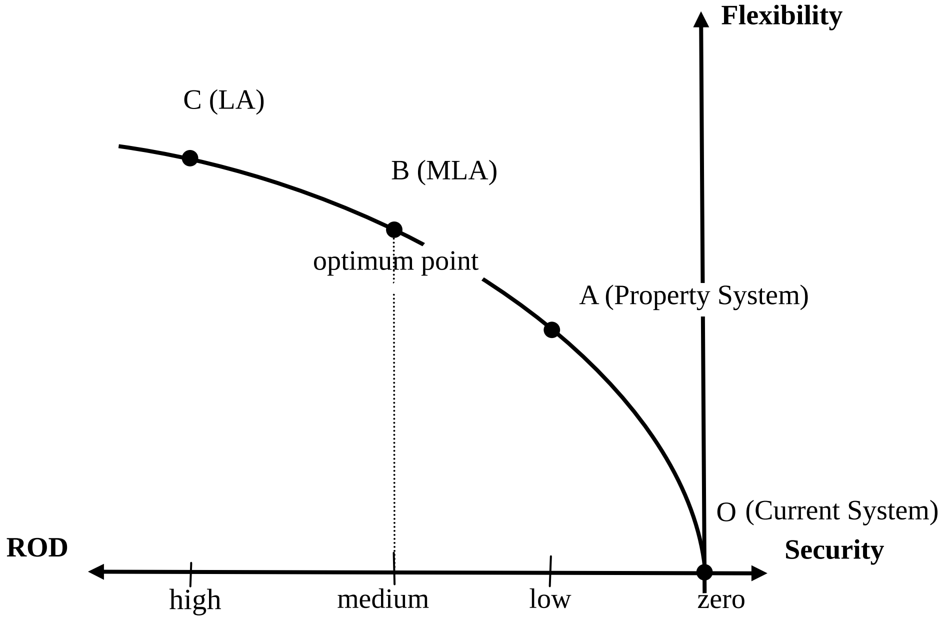

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Figure 4: Example of Spectrum Usage (MLA) Note: Entries in *italics* are introduced anew in this example.

	Spectrum Band	Band A		Band B				Band C		Band D	Band E
ALLOC	Objective	Broadcast		Commercial Mobile			*Unspecified*	Security	*Internet Access*	Internet Access	Unspecified (ISM)
	Priority	Primary		Primary			*Secondary*	Primary	*Secondary*	Primary	Primary
	Mode-G	Exclusive		Exclusive			*Commons (UWB)*	Exclusive	*Exclusive (overlay)*	*Exclusive*	Commons
ASSGN	License (Spectrum Block)	A1	A2	B1	B2	B3	*BB*	C	*CC*	*D*	*E*
	Duration	10yrs		5yrs			*5yrs*	5yrs	*5yrs*	*5yrs*	*5yrs*
	Spectrum User (Licensee)	Broadcast Stations		Mobile-phone Providers			*Public Agent*	Police, Fire Stations	*Union of Internet Access Providers*	*Union of Internet Access Providers*	*Public Agent*
	Mode-L	Club/ commons		Club			*Commons*	*Club*	*Club*	*Commons*	*Commons*
	Lease price			*(Determined by auction)*							
	Amount ROD-insured (Relocation cost)			*(Specified by spectrum user)*							
Final user		Consumers, etc., of Services using Spectrum									

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Figure 5: Example of transition (case of M=5, M=10, M=20)

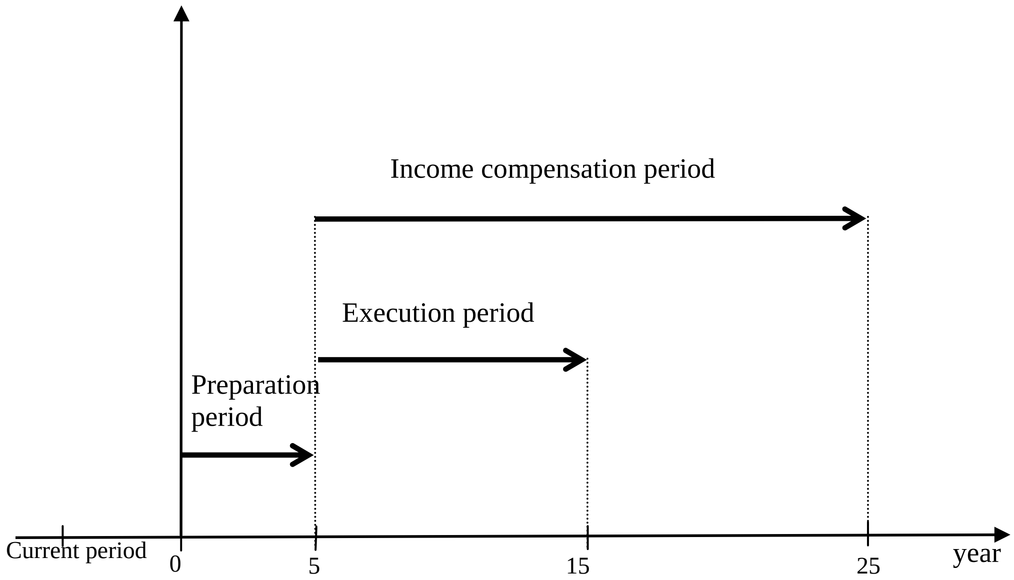

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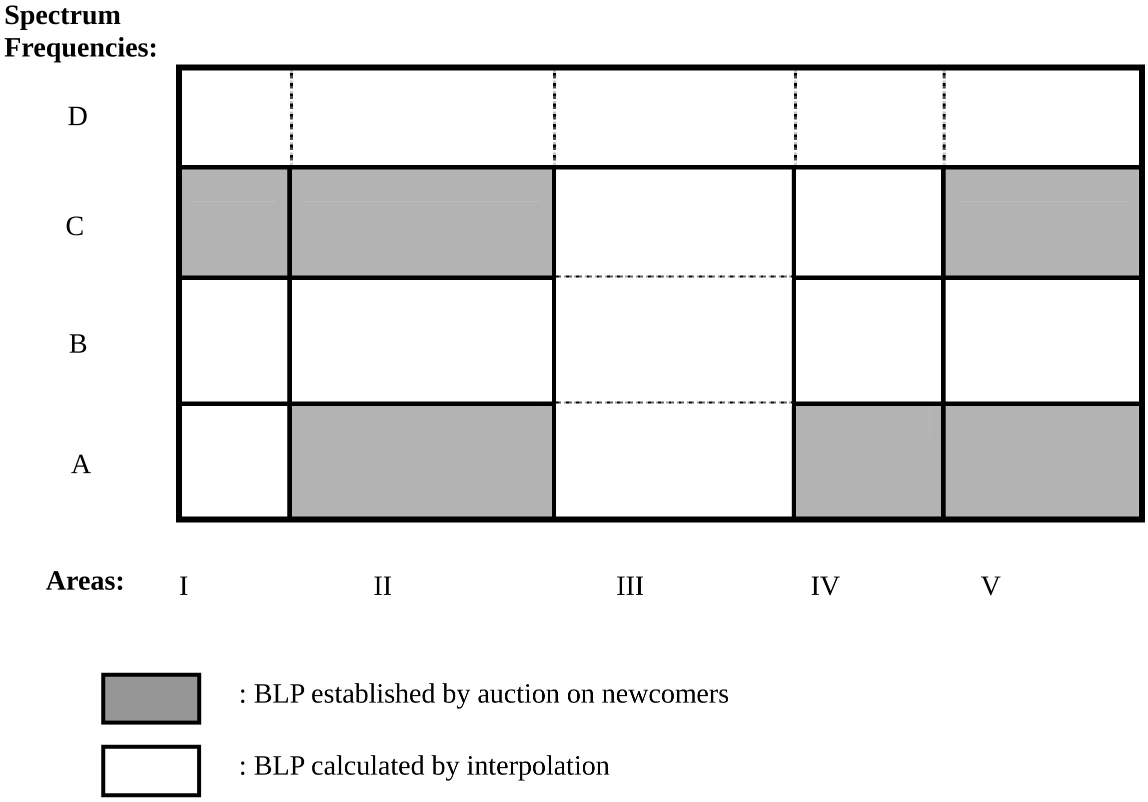
Figure 6. Establishing "benchmark lease prices (BLP)"



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