DRAFT: Modified Lease Auction and Relocation---

Proposal of a New System for Efficient Allocation of Radio–spectrum Resources

International Conference on Convergence in Communications Industries

Warwick University

November 2-4, 2002

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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 is composed of two parts.

The first part proposes a system called “modified lease auction (MLA)” as a long-run target. In this system, the government is the sole owner of spectrum and leases (rents) it competitively to users, private or public. Thus, not only initial but also successive licenses for the use of spectrum are assigned by auction on the lease price. The system can accommodate various modes of spectrum use: exclusive, shared, or commons mode. A serious disadvantage of adopting MLA 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. The paper proposes ways to protect incumbent users from ROD.

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

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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 equilibrium and efficiency in the future.

Radio spectrum was first used about 100-years ago for navigational safety and navy operations. Ever 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 1050s, 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.

Such remarkable development of the utilization of radio spectrum was achieved,

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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.

Throughout this process, the management of radio spectrum was in the hand of the central government in almost every country. For one thing, the major concern in the management of spectrum was how to prevent interferences between spectrum users; this called for public regulations. For another, spectrum was first used for safety and military purposes; it was natural for the government to play the role of managing it. Furthermore, since new utilization of spectrum was made possible by an expansion of the spectrum frontier, there was rarely a case of spectrum scarcity or a conflict in the utilization of spectrum between users; the effective price of the spectrum was near zero. Thus, the government was simply able to yield away the right to use spectrum blocks free of charge.

Until recently, the principle of government control 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, there has been no rent charged by the government from users of spectrum except nominal charges for covering the cost of management. In short, the world of radio spectrum has been a socialistic island in the ocean of economic activities taking place under the principle of market mechanism.

This situation, however, changed in the 1990s. As the speed of technological progress for utilizing radio spectrum was increased, the demand for spectrum grew exponentially for new services such as mobile telephony and wireless internet access. Roughly speaking, by the beginning of the 21st century, the frontier of 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 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

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unused or used very inefficiently. During the time of the frontier expansion, it was of little concern for the government to have spectrum bands used efficiently. Furthermore, it was not a concern of users to save spectrum since the price was near zero, except with such users as mobile telephone operators for which the supply of spectrum was not sufficient relative to the number of mobile subscribers. As a consequence, the state of utilization of radio spectrum at the present time is in disequilibrium; some spectrum is used efficiently with the expenditure on new equipment, but other spectrum is used inefficiently with old and obsolete equipment. This situation may be compared to a case in which a large size of farmland is found in the center of London or next to the Empire State Building in New York. Such a case would not arise in the use of land because it would be precluded by the market power. For the case of radio spectrum in which the market power is not working, we can and do have extremely unbalanced utilization.

The challenge we face today is to find a way to get out of such inefficient disequilibrium. It is clear that, since the frontier has been exhausted, some relocation of radio spectrum between incumbent and new users is unavoidable. Needless to say, there will be a strong opposition to this by incumbents, who have been using spectrum free of charge for years and have vested interest in it in the form of equipment and devices and other forms of investment.

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. We will propose a system to be called “modified lease auction (MLA),” in which the government retains the ownerships of radio spectrum and leases it to users according to the auction on lease prices. In order to remedy shortcomings of the lease system, some modifications will be introduced to it, hence the naming of modified lease auction. 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 give a way to compromise political oppositions by incumbent spectrum users, a proposal 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.

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In the following section, Section II, a summary will be given on the system of spectrum utilization at the present time. The proposal of this paper may be regarded as a number of changes to be applied to the present system. In Section III, the system of modified lease auction (MLA) as the long-run objective will be given. It is noted that MLA can accommodate various modes of spectrum utilization such as exclusive use, shared use, and commons use. In Section IV, a scheme for transition from the present system to MLA is described. It is composed of two procedures. One is a stepwise increase in the lease price from the present level of zero to the equilibrium of market price. The other is a scheme for income compensation. The last section, Section V, gives a summary of economic properties of radio spectrum, which will be considered as one of what may be called “space resources” such as land space, air space, the space of satellite orbits, and others.

II. Factors Characterizing the Usage of Spectrum Bands and Blocks

In this section, we summarize the present system of spectrum utilization; to do this, we consider the factors characterizing the usage of spectrum bands and blocks. The proposal to be made in this paper would greatly change, on the other hand, the substance of spectrum utilization in that it introduces lease auction and other market elements. On the other hand, however, it would not change much the formality of spectrum utilization. Thus, 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 in this formality the proposal of this paper intends to introduce changes.

A. First-stage specifications (allocation of spectrum bands, ALLOC)

The utilization of radio spectrum today is administered by the government in two stages; the first stage is the allocation of spectrum bands (ALLOC), and the second stage is the assignment of spectrum blocks (ASSGN).

The ALLOC stage specifies a portion of radio frequencies (to be called a spectrum **band** in this paper). A band specifies a range of radio frequencies, a geographical area, and a time of the day or of the weak, in which it is used. Further, a band is given one or more objectives for which the band is to be used. An example of ALLOC (and ASSGN) is given in

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Figure 1. As the objective for spectrum usage, it gives “Broadcast” for Band A, “Commercial Mobile” and “Unspecified” 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.

Occasionally, the right to use a band is divided into two categories: primary use and secondary use. A primary user has the right to use the band as desired; 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. In the example given in Figure 1, a user of Band A has both primary and secondary rights, whereas for Band B, primary and secondary uses are distinguished[1].

In addition to the objective and the priority of using spectrum bands, this paper proposes to consider an additional category; **usage mode**. Four usage modes are introduced; exclusive use, shared use, commons use, and unspecified use[2]. In the exclusive use, there is only one spectrum user who is allowed to use the band exclusively. For the shared use, there are two or more users of the same spectrum band; the way in which the users coordinate to share that band is specified by the government as one of ALLOC specifications. The commons mode of spectrum utilization, as the naming indicates, is an open and free use by unspecified users as in the case of a town commons used by many people. The rules for using a spectrum band under the commons mode may be specified by the government.

The exclusive mode of spectrum utilization is typical in the current system. The shared mode is also seen for many spectrum bands with restricted entry such as microwave communication, or with unrestricted entry such as those allocated for marine or air transportation. The spectrum band for the 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”. Today, there are strong advocates for introducing the commons use, emphasizing the technological progress achieving new ways of utilizing spectrum such as

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[1] ITU has introduced, in its spectrum allocation table, the two categories of primary use and secondary use. The latter is called “easement” by Faulhaber and Farber [2002].

[2] Needless to say, each of the four modes has been discussed extensively by many authors. What is proposed in this paper is to introduce a category called “usage mode” explicitly as an element in ALLOC.

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"UWB" and "overlay[3]". This paper fully recognizes the possible advantages which may be brought in with commons modes; the system of MLA to be proposed in this paper can accommodate a commons mode of utilizing spectrum within itself as explained in section III[4].

In addition to the specifications at the ALLOC level as explained above, there would be many technical specifications including power emission, data transmission method, standardization, etc. The proposal in this paper takes such technical specifications as given today at least in considering the short-run ALLOC specifications. It will propose, in Section IV, a principle according to which technical specifications may be revised and improved in the long-run ALLOC specifications.

B. Second-level specifications (assignment of spectrum blocks, ASSGN --- licensing)

The second stage of specifying spectrum utilization, ASSGN, first divides each spectrum band determined in ALLOC into one or more spectrum **blocks**. The block is the actual unit of spectrum to be assigned to users. To the user of each spectrum block 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. In U.S., U.K., and other countries, as known widely, attempts have been made to select licensees by auction. In the proposal of this paper, licenses are to be issued solely by lease auctions.

In the example of Figure 1, Band A is divided into two blocks with licenses L-A1 and L-A2. The primary use of Band B is divided into three blocks, L-B1, L-B2, and L-B3. The secondary use of Band B, however, is not divided and a single license L-BB is to be issued for it.

Each license has its duration indicating at what date it becomes effective and at what date it is terminated. In Figure 1, each of the two broadcast licenses on Band A has a duration of 10 years, whereas each of the three blocks of primary use with Band B for commercial mobile services has a duration of 5 years.

In the present-day system, the duration of a license is formally specified, but its actual

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

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

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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. Such understanding did not bring in problems at the time the supply of spectrum was abundant and its effective price was zero. However, once the supply has become tight and the effective price of spectrum is no longer zero, such semi-automatic renewals of a license has given its holder an economic advantage and vested interests.

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

The rights and responsibilities accompanying a license including the power limit for specifying spectrum boundary should be determined before the license is issued. There will be a large number of technical specifications in relation to this. Further, once a license is obtained by an auction, there should be no restriction on the right to sell or sublease it.

III. Spectrum Relocation by means of Lease Auction (MLA) ---The Long-run Objective

A. Outline

This section explains in detail what this paper calls “modified lease auction (MLA)”. MLA is the long-run objective in the following sense. The present system is under the government planning; it is a zero-price lease with high probability of repeated renewals. The system to be proposed in this paper, MLA, is under the control of market power (i.e., auctions); further, it is a lease of clearly stated duration. The distance between the two systems is quite large; there is no way to jump from the present system to MLA. We need a scheme for gradual transition, which will be presented in the following section, Section IV. The system of MLA to be presented in this section, therefore, is the one which would be considered if a system of spectrum utilization were designed from scratch.

In the following, we distinguish three aspects of ALLOC and ASSGN: the ALLOC specifications in the short run, the ASSGN specifications, and the ALLOC specifications in the long run.

Roughly speaking, the ALLOC specifications in the short run in the proposed system

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will be the same as the one in the present-day system. In the ASSGN specifications, the main difference between the present-day system and the proposed system lies in the selection of spectrum users and the determination of the lease price; the proposed system introduces auctions to determine the user and the price in replacement of the government control in the present-day system.

The long-run ALLOC specifications in the new system differ from the present-day system in that the former uses the lease price in relocating spectrum bands, and also in that the former introduces an insurance scheme to protect spectrum users from the impact of possible relocation.

B. ASSGN by means of (simple) lease auction (LA)

Let us first define the (simple) lease auction (LA). 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 the lease be applied to all users including private, public, and government users; there should be no exception to this principle. Auction should be applied to each spectrum block, which is specified by a frequency range, geographical area, priority, time of use, etc. Once a user obtains a license for using a particular block of spectrum through an auction, the licensee is allowed to sell or sublease it within the ALLOC and ASSGN specifications.

A lease auction system can accommodate various usage modes.

When a spectrum band is designated for exclusive use, then the winner of the auction would simply become the user of it. Shared or commons use can be realized by the government through ALLOC specifications or through a (private) arrangement made by a user of an exclusive or unspecified block. In this case, the (private) user, upon winning an auction, would choose to let the spectrum block be used by its customers, etc., in shared or commons mode. A typical example would be that an internet service provider wins an auction of a block of spectrum and uses it to supply wireless internet access services to subscribers with some charge. In fact, the way in which the present-day mobile phone provider let the subscribers share the spectrum block is close to this example. Thus, the choice (and the creation) of a usage mode is under the hand of the user in this case.

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This paper proposes to let private and government users make arrangements as to the choice of a usage mode. Users of spectrum blocks would then compete each other; as a consequence, whichever is more efficient would prevail in the long run.

An example of government-arranged shared use is the primary use of Band C in Figure 1. In this case, the primary right would be given to government and other public users such as police, coast guards, fire stations, and others. The Band-C primary license may be won in auction by a government entity representing them. If such a band is “very important” and must be secured for them, then it is expected that a large amount of budget would be allocated to the government entity representing the security agents so that the entity could win the auction for the block. This is a way to introduce market mechanism into the use of radio spectrum by public agents. It gives us two advantages. One is that the value of the spectrum would be exhibited by the lease price, which would give a signal for spectrum relocation through the long-run ALLOC. The other advantage is that it gives an incentive to save spectrum use. The way that this block is shared is determined through the short-run ALLOC specifications.

There are two types in the commons use. Type-1 of commons use is like the unlicensed one at the present time. It is for the use within a household such as wireless telephone, home wireless LAN, and electric ovens. In Figure 1, Band E is designated as type-1 commons use; the objective of this band is unspecified and a single license, L-E, is to be won by, say, a union of the suppliers of devices using this block. In this case, union membership should be open and members of the union should pay the lease price according to a predetermined scheme. In effect, such a union would become a half-public, half-private entity.

Examples of type-2 commons use are what is called UWB (Ultra Wide Band) and overlay. They are for a secondary right to exploit the vacant potion 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 the same band. Overlay uses what is called 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 1, the secondary right to use Band B would be obtained by a government agent (through auction); the secondary right would then be released to UWB uses. The lease price for this is to be paid from the general tax so that, in effect, the

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UWB service is regarded as a public good. That is to say, like other public goods, the cost of supplying UWB is paid from the government budget. In auction, the government agent administering this activity would be allowed to bid up to the amount of budget allocated to it.

In Figure 1, the secondary use of Band C is also specified as this type of commons. In this example, a union of internet access providers would possess the License L-CC; the block is devoted to the internet access services. Since L-CC is of 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 right 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. Further, in Figure 1, Band D is designated to be of unspecified mode and the license L-D might be obtained by the union of internet access providers. The union, of course, would use this block in a (privately-arranged) commons mode.

IV. Modified Lease Auction (MLA) for ASSGN and Long-run ALLOC

This section will be devoted to explaining the system of modified lease auction (MLA) in detail. First of all, in order to fix up a shortcoming of the system of (simple) lease auction (LA), two modifications will be proposed. We then discuss how the government revises the long-run ALLC for relocations. In later parts of this section, economic implications of the need for the modifications will be discussed by comparing MLA with the property-right system.

A. Disadvantages of LA

The obvious advantage of introducing lease (LA) in the use of radio spectrum lies in its flexibility. That is to say, in comparison with the government-control system or with the property system, LA makes it easy for bands and blocks of spectrum to be relocated from old to new users according to the need arising from technological and economic changes.

There is a serious disadvantage, however, in the system of LA. From the standpoint of a user of spectrum, it would be desirable to be able to use it in the future indefinitely, since such would protect investment of the user made the past. In other words, LA would impose the spectrum user the risk that the license might be terminated undesirably. We call it the risk of lease discontinuation (**ROD**).

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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 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 user of the spectrum could continue to use it at least until the investment made in the past would be fully recovered. Under the system of LA, the incumbent user could not do this. This is ROD1.

The second category of ROD arises from a long-run ALLOC decision by the government. When the government decides to change (for a good reason as explained later) the objective for using 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 could 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. We will discuss about implications of risk more in detail later in this section. In the following, we will propose modifications of LA so that the shortcomings arising from ROD1 and ROD2 may be remedied at least partly.

B. Protecting incumbents from ROD1 to an appropriate degree

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

(a) 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 the 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 the incumbent carried over from the past. To find an appropriate percentage of discount, trials are errors would 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.

(b) 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

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the investment made in the past, it is easier for incumbents to make a decision on the demand price for a license for using the spectrum in the future than for newcomers starting from scratch.

(c) 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,” or more precisely, like auctioning on a “fee for partial reservation.” This is, in effect, a combination of (a) and (b) above, since this would protect incumbents in terms of both the amount of money to be paid for lease and the timing of decision.

(d) To create futures and/or options markets for the right of leasing spectrum. This is an extension of (b) above. The 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 as the one having been used in the past.

We can think of other ways for protecting incumbents from excessive ROD1. This may be a possible research subject in the future.

C. 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 in the ALLOC specifications. As stated previously, the government would change ALLOC specifications in the long-run in such a way that, in principle, 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 would have to 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 given to the band and initial assignments of licenses for the band would be determined 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 for using it. In other words, ROD2 is a risk arising not from the insufficient competition capability of the user, but from the insufficient

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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 entire demand and the supply of the 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, a spectrum user would determine the amount to be paid in case a discontinuation of the lease took place. This amount should reflect the sunk part of the investment having been made for using the spectrum and not having been recovered through depreciation allowances and other means. In other words, the amount insured should 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. It is proposed that the amount of insurance fee be equal to the product of an insurance-fee rate, to be discussed immediately, and the amount of money insured.

It is further proposed that this spectrum insurance program be run by a government agent. The agent would determine an insurance-fee rate 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.

D. Long-run ALLOC decision by the government

By revising the long-run ALLOC specifications, the government can relocate spectrum bands from inefficient use (with low prices) to efficient use (with high prices). The choice of the speed of relocation, i.e., approximately what percentage of the entire spectrum be relocated per year, may be determined by comparing (a) the estimated increase in the present value of the total lease fees to be collected in the future on the reclaimed bands, and (b) the amount of total insurance payments for reclaiming the bands. In short, the government should make a decision on the long-run ALLOC specifications so as to balance the annual budget for annual reclamation (relocation). In this way, the government could simulate the working of market mechanism on the long-run allocation of radio spectrum, thus achieving an optimum outcome.

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Needless to say, however, in doing this actually, there would be many imperfections and costs (including transactions and systems costs); the government would have to rely on discretions at many points of its decision in revising the long-run ALLOC specifications.

E. Further considerations of ROD

Let us consider here economic meanings of ROD. ROD arises when the spectrum user is forced to give up using spectrum bands/blocks 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; there would be no ROD if the economy were stationary (stagnant) so that the economic activities in each year were exactly the same as the economic activities in the preceding years. ROD is a price which we have to pay in order to achieve flexibility in spectrum use. Thus, the degree of ROD determines the balance between the security to incumbents and the chance of entry by newcomers. We can state that we face a tradeoff between flexibility and security in using radio spectrum; we need to choose a point on a curve representing the tradeoff.

Figure 2. illustrates this tradeoff. We point out that the level of ROD is near zero in the current system (central planning by the government). It is low but not zero in the property system. In (simple) LA, the level of ROD is quite high, since incumbents are not protected at all. We can conclude that MLA provides us with a medium level of ROD. Actual choice of ROD should be made by the government through successive adjustments, i.e., by trials and errors.

In addition to the presence of ROD, there is a reason that we favor (modified) lease auction over the property system with free spectrum trade. It is the presence of externality in the use of radio spectrum. Spectrum resources, as other space resources (see the last section, section VI), exhibit positive externalities in the sense that, if spectrum bands or blocks were put together and placed under a single control, the outcome (benefit) from the integrated spectrum would be higher than the sum of the outcomes from the spectrum used separately. For the case of land space, we have familiar examples such as the residence capacity of apartment buildings and the traffic capacity of multi-lane highways. For the case of radio spectrum, an example of positive externalities may be the case of CDMA for distributed transmission of signals. Rather,

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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 devices for TV.

Note that the range of spectrum bands/blocks which exhibit significant positive externalities 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 multiple spectrum bands or blocks into one.

Now, under the system of property rights, when such an integration is attempted through spectrum trade, it is possible that the owner of a small piece of spectrum charges excessively high price for it, as we see in the case of land from time to time (hold-up case). Relocation of spectrum would be obstructed, then.

In the Arrow-Debreu world in which perfect and exhaustive contingency markets existed, such a problem would be solved in Nash equilibrium with Coase's theorem. In reality, of course, the transactions cost (organization cost) of having such perfect markets is high; we have to live with a system of imperfect markets and to simplify a large number of contingencies into the reality of negotiations and decision making with different information sets for each party; i.e., risk and uncertainty cannot be avoided. The consequence is, as experiences show, 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. To avoid costs arising from hold-up cases, we prefer MLA to the property system[5].

Similar arguments may be applied to the need for protecting incumbents from ROD. If markets with perfect contingencies existed, then there would be no ROD and no need for favoring incumbents or arranging a spectrum insurance. Research for determining "optimal degree of protection against ROD" may be a subject for future research.

[5] There is a case in which it is possible to bring the benefit of positive externalities in the presence of spectrum hold-up; the user would bypass easily by means of software-defined radio (SDR)(See footnote 3). Therefore, once SDR becomes not only an engineering goal but also economic reality, the reason for preferring MLA to the property system would be weakened (but not lost). However, there is a cost in time and money for introducing SDR; thus the issue of MLA versus the property system may be regarded as a tradeoff between the cost of bringing in SDR and the length of lease duration.

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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 preceding sections, MLA has a number of desirable characteristics over the current system (government planning). 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 have made a large amount of investment in the form of equipment and devices, human skills, social institution, etc., which cannot 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 by using depreciation allowances and other means.

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, each user should be informed fully of the process of transition so that each user can 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 excursion 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 3 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.

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B. Formation of benchmark lease price (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 bands by a range of frequencies and by a geographical area with, if necessary, a time and a mode. Figure 4 gives an illustration with a simple case in which the frequencies and the areas are represented by a horizontal axis and a vertical axis, respectively. Furthermore, Figure 4 represents a case in which the division of frequencies and the division of areas are done independently. In Figure 4, Spectrum Band III may be a broadcast band or an unlicensed band; there is no geographical division for that band. Further, in the example of Figure 4, Bands IV and V are not divided in Area D.

The gradual formation of BLP might proceed as follows. During the preparation period, 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 relocation of spectrum would be involved. Suppose in Figure 4, 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 the 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 possible, 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, say, each month or each quarter.

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.

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During the preparation period, new users of spectrum would pay lease fees as determined by auction. The incumbents, however, would pay nothing except that they would be informed of the BLP of the spectrum blocks they were using.

Furthermore, during the preparation period, the government might encourage incumbents to return a potion of the spectrum they were using to the government; incentives might be provided for this. An example of such an incentive might be a discount of the lease fees that the incumbent would have to pay during the execution period. It is expected that those blocks with low efficiency would be returned by incumbents; returned blocks should be put to auction for newcomers, thus increasing the number of gray rectangles in Figure 4.

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). According to this scheme, the incumbents could adjust their use of spectrum gradually. They might return to the government a potion of the spectrum blocks they were using, they might employ more efficient equipment to save the spectrum need, or they might shift to other means for communication such as optical fibers.

By the way, we propose that, during the execution period, the incumbents would face no ROD; they would be allowed to continue using all of their spectrum blocks until the end of the execution period, should they choose to do so.

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 and thereafter. In particular, all licenses would have to be issued under MLA upon expiration, and the incumbents as well as newcomers would face ROD. Furthermore, once the execution period is over, the users of spectrum would be allowed to sell or sublease licenses as desired.

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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 to the introduction of MLA strongly. This is an issue of income distribution between the incumbent spectrum users and the rest of the society. As such, there is no economic theory to justify or unjustify the change in income distribution caused by introducing MLA.

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 by avoiding likely oppositions by incumbent 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 others. 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[6].

Let us begin with reminding of the definition of the compensation period; Figure 3 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 in period *t*. Observe that *BAP(t)* would vary over time as PLP or *FLP*, but the spectrum 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

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

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

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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* 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 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)*.

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 was 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 (subsidy) from the government. But note that the government would never be in deficit 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. In other words, the income compensation scheme as

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proposed here is independent of the non-income effects of MLA and 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. 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 decrease. 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. 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: Example of Spectrum Usage --- ALLOC and ASSGN Note: Items with (*) indicates that they are proposed anew in this paper

Spectrum Band (Frequencies, Area, Time)		Band A		Band B				Band C		Band D	Band E
ALLOC	Objective	Broadcast		Commercial Mobile			Unspecified	Public Safety —Emergency Use	Internet Access	Internet Access	Unspecified (ISM)
	Priority	Both		Primary			Secondary	Primary	Secondary	Both	Both
	Usage Mode (*)	Exclusive		Exclusive			Commons (UWB)	Shared	Commons (overlay)	Unspecified	Unspecified (“unlicensed”)
ASSGN	License (Spectrum Block)	L-A1	L-A2	L-B1	L-B2	L-B3	L-BB	L-C	L-CC	L-D	L-E
	Duration	10yrs		5yrs			5yrs	5yrs	5yrs	5yrs	5yrs
	Spectrum User (Licensee)	Broadcast Stations		Mobile-phone Providers			Government Agent	Government Users	Union of Internet Access Providers	Union of Internet Access Providers	Union of Device Suppliers
	Lease Price (*)	(Determined by Auction *)									
	Amount ROD-insured(*)	(Specified by Spectrum User *)									
Final user		Consumers, etc., of Services using Spectrum									

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Figure 2: Tradeoff between ROD and Flexibility in the Use of Spectrum

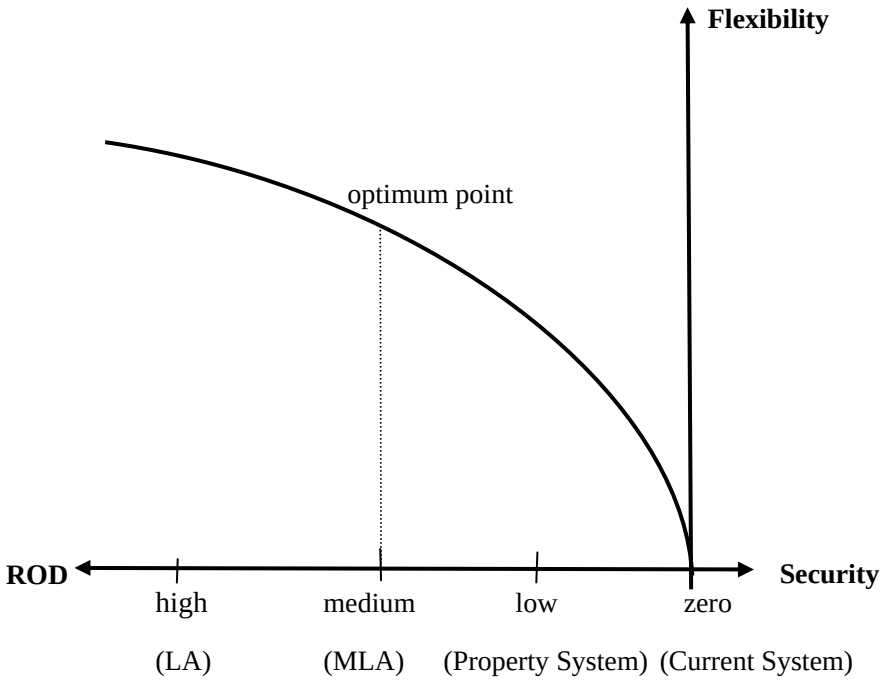

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Figure 3: Example of transition (case of M=5, M=10, M=20)

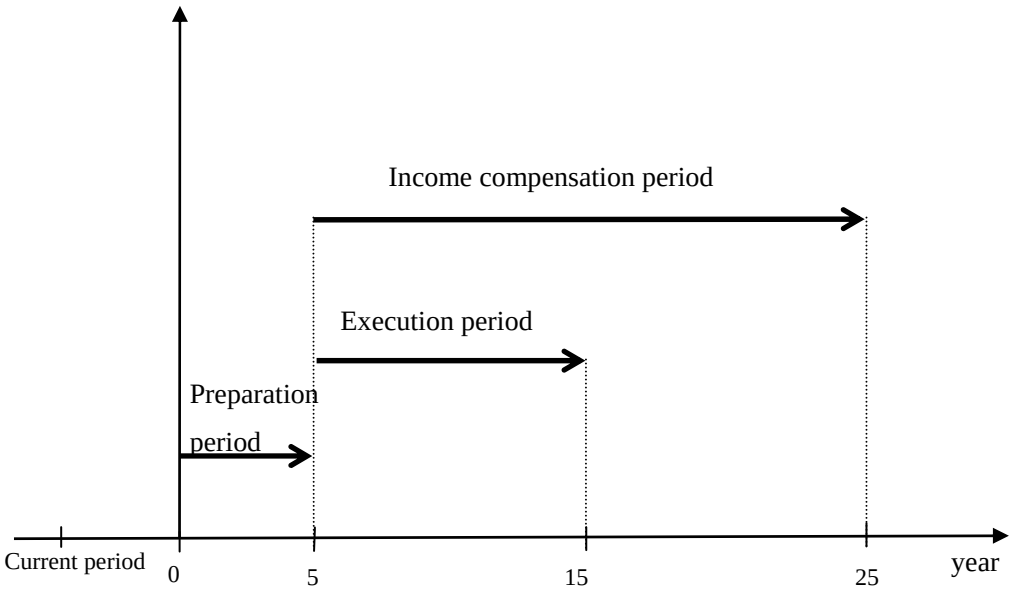

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Figure 4. Establishing "benchmark lease prices (BLP)"

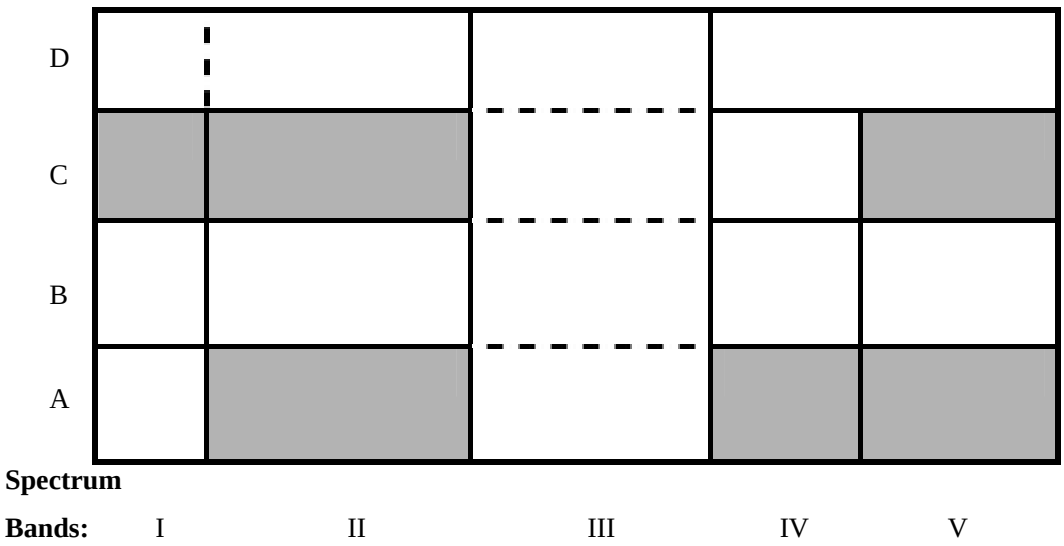

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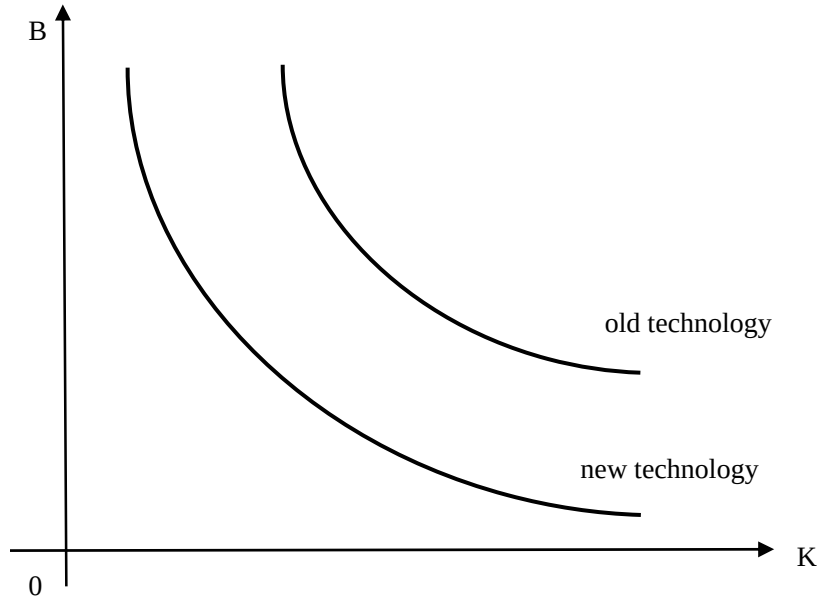
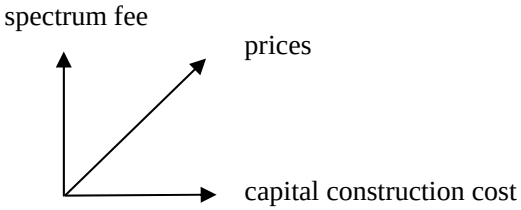
Figure 3: Iso-service tradeoff between equipment capital (K) and spectrum bandwidth (B) with given technology for commons use





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