Hajime Oniki
3/3/2006

On Efficient Assignment of Radio–spectrum Resources

February 2006

Hajime ONIKI

Osaka-Gakuin University, Japan

Abstract

This paper considers 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 propose a system called "modified lease auction (MLA)." 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, club, or commons mode. A serious disadvantage of MLA is that the incumbent spectrum user faces the risk of discontinuation (ROD); i.e., the user, at the time of license renewal, 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 to a justifiable extent.

The paper also 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 near zero 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.

I Introduction and Background

A. Radiowave resources

In this paper, radiowave spectrum is considered as an economic resource. Radiowave spectrum covers the electro-magnetic waves of which the frequency ranges from 3KHz to 300GHz. Radiowave spectrum is used widely for communication and other purposes. Because of the advancement of wireless technology during recent years, the use of radiowave spectrum has become indispensable in our daily life and business.

Let us first summarize the properties of radiowave spectrum viewed as an economic resource. First of all, 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 like

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

machines and equipment in that it does not depreciate. Radio spectrum, however, is not a resource of unlimited supply.

In order to understand the supply, or in general the quantity, of spectrum, it is useful to consider its resemblance to land as a resource. Land is a non-reproducible, non-depleting natural resource with limited supply; in addition, a piece of land has boundaries and a size. In fact, both land and spectrum as economic resources can be grouped 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 resemblance of radiowave spectrum to land is a consequence of the fact that the utility of land arises from using a portion of the surface of the earth physically, whereas the utility of spectrum arises from using a portion of the surface of the earth electro-magnetically (terrestrial spectrum), or from using a portion of the geo-stationary satellite orbit electro-magnetically (satellite spectrum). Thus, the term "spectrum" means, in many cases, not electro-magnetic waves themselves, but a space for electro-magnetic waves to propagate through.

In order to utilize spectrum, we need to rely on some technology. In fact, for almost all cases, we need to use devices such as a receiver and a transmitter for wireless communication. Observe that the use of land also depends on technology, and, of course, we need to use some means such as buildings or transportation equipment to derive utility from land. In short, we need some capital stock for using a space resource, be it land or spectrum.

Technological progress enables us to utilize land or spectrum more efficiently; examples are skyscrapers or multi-lane highways for using land and technologies developed recently for using a given spectrum more efficiently such as spread spectrum, software radios, and UWB. Further, externality is a property commonly observed in using land or spectrum as an economic resource. Land exhibits positive externalities in the form of economies of scale area-wise, and similarly spectrum exhibits positive externalities frequency-wise as well as area-wise. Further, both have negative externalities arising from excessive use of a space; they are called congestions for land or interferences for spectrum.

B. History

The invention of wireless technology was accomplished toward the end of the nineteenth century. In the beginning of the twentieth century, spectrum was used for navigational safety and navy operations. Ever since that time, the utilization of spectrum has expanded steadily. In the 1920s, voice radio became popular, and in the 1940s, during the war, radar was invented.

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

Since the 1950s, television receivers have become a major household good. Today, in many countries, mobile telephony shows penetration far 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 accomplished, needless to say, by a succession of technological advances. Typically, a new technology was invented by making use of a new band of radio frequencies which had so far been unused. In other words, the development of wireless technology was an expansion of the frequency-frontier of spectrum utilization. The issue to be dealt with in this paper arises from the fact that this frontier has nearly been exhausted. To be more precise, we should say that there remain many bands unused or rarely used in high frequencies such as in micro-wave frequencies. However, with today's technology, these high-frequency bands are not so easily or economically usable. In comparison with this, spectrum bands of medium frequencies such as those below 3GHz (including VHF and UHF) are quite useful to us and the demand for these frequencies exceeds the supply, especially in urban areas. As a consequence, the right to use spectrum in VHF or UHF bands in urban areas carries a high economic value now.

C. Management of spectrum

In this sub-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 one 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.

The utilization of radio spectrum at the present time is administered in two stages; the first stage is allocation of spectrum *bands* for specific objectives and the second stage is assignment of spectrum *blocks* to users. *Allocation* of spectrum is done in two levels, international and national. International allocation of spectrum is conducted by the International Telecommunication Union (ITU) and by other international bodies. At this level, overall allocation of spectrum bands is agreed upon by member countries; a recent example of such agreement made by ITU is the specification of a certain band in UHF for the use of RFID. The national level of spectrum allocation is made by national government, which specifies one or more objectives for using a spectrum band in more detail together with technological specifications including the power of radio emissions, the allowance of interferences, and the format of modulation and coding needed for information transmission.

An example of spectrum allocation is given in the upper half of 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.

<*** Figure 1 here***>

The need for spectrum allocation arises from the presence of positive and negative externalities in using spectrum. It resembles to “zoning” in city planning for using land spaces. If there were no externalities in using spectrum, there would be no need for ITU or national government to allocate it. It is noted that, in general, technological advances contribute to promoting the benefits from positive externalities and to preventing the harms from negative externalities. Thus, the need for spectrum allocation is expected to vary (usually decrease) with technological advances.

The second stage of managing spectrum resources is *assignment* of a spectrum block to users. Typically, a spectrum band is divided into a number of spectrum blocks, frequency-wise and area-wise, to each of which a single user or multiple users are assigned with or without a license. An assignment also specifies the time (of a day, a week, etc.) in which spectrum is used together with technological specifications. A 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 the lower half 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.

The license has its duration indicating at what date it becomes effective and at what date it expires. 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 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 expiration 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.

Historically, the main objective of allocation and assignment was to prevent interferences among spectrum users, and also to promote efficient utilization of spectrum in consideration of positive externalities. During the time in which wireless technology was advancing ahead of spectrum needs, the task of allocation and assignment was easy, since the supply of spectrum exceeded the demand. Once spectrum shortage emerged, however, the situation changed enormously; ITU and the national government must now solve a difficult problem how to satisfy the demand for spectrum resources which exceed the given supply. The subject to be dealt with in this paper has become important because of this.

D. Modes and institutions for spectrum management

In this subsection, we consider various modes and institutions for managing spectrum resources. Much has been debated on this subject during recent years.[1] The objective of this subsection is to give a summary for the discussion in this paper.

The first mode for spectrum utilization is the *exclusive use*, in which a spectrum block is assigned exclusively to a single user with a license. In Figure 1, Band A and the primary use of Band B are given the mode of exclusive use. For exclusive utilization of spectrum, we distinguish two institutions; the first is command and control and the second is market mechanism.

Command and control is the traditional system of spectrum management having been adopted in many countries. After a spectrum block is established with specifications regarding a frequency range, an area for use, and the emission power and other technical specifications, the user of a block is selected according to the first-come basis, random selection (lottery), or comparative hearings (beauty contest). The license for using a block is of a limited period of time, but usually it is renewable. Typically, there is no rental or lease payment imposed on a user except that nominal fees may be charged by the national government for the cost of document processing, database maintenance, and policing to prevent interferences.

The second of the two institutions for spectrum assignment is *market* mechanism, in which the law of demand and supply with prices functions to control the right to use a block. In one system, spectrum is treated as a private property in the same way as land is in many countries. In this system, auction may be used for initial assignment of spectrum and market transaction of the right to use a block is allowed. As a consequence, secondary property markets and also secondary lease markets for spectrum may emerge.

The other system of market mechanism for assigning spectrum blocks is the competitive lease and renewal by national government, which is the objective of the discussion in this paper and will be treated in detail in the following sections. In short, the national government remains to be the owner of the spectrum resources and leases spectrum blocks competitively to users. Lease prices may be determined by auction; in this case the government needs to consider some way to protect incumbent users at renewal auctions. Further, secondary markets may develop for transacting the right to use a spectrum block[2].

In comparing market mechanism with command and control as a means to assign a spectrum block, it is agreed upon widely that market mechanism is better than command and

---

[1] See, for example, Cave [2002], Faulhaber and Farber [2002], Hazlett [1998], and FCC [2002].

[2] See FCC [2003, 2004] for a system of secondary markets of spectrum lease being introduced in U.S.

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

control in promoting efficient utilization of spectrum resources.

The second category of the modes for using spectrum blocks includes club and commons. In both of these, multiple users are assigned to a single block. The difference between a club and commons lies in the degree of freedom for new entry. In the *club* use, new entry is unrestricted or restricted by the government. It is customary that a license is issued to club users. Typical examples are amateur wireless communication and wireless communications used for public safety or for the safety in navigation or aviation. In Figure 1, the primary use of Band C is designated as a club. To avoid interferences, a club user is allowed to use a communication channel only when the channel is not used by others. For this reason, we may characterize a club use to be a time-shared exclusive use.

A spectrum block for *commons* is opened to the public for free use under technical restrictions such as very weak power emission. Interferences between users are avoided, if not completely, as a consequence of these technical restrictions. No license is required in commons (hence, *unlicensed band*). Typical examples of commons are the ISM band and the bands for wireless LAN, wireless Internet access, and RFID. Figure 1 gives a number of examples of commons: the secondary use of Bands B and C for UWB, Band D, and Band E.

Club and commons can be realized under command and control or under market mechanism. A typical case at the present time is the one under command and control, in which ITU and national government designate a block to be of club or commons use; no fee is charged from users. A club or commons under market mechanism may be supplied by a public agent. Such an agent would represent the aggregate interest of the users of the block; the agent would first secure the right to use it exclusively in the spectrum market and would then offer it as a club or commons. The cost needed for the agent to secure the block would have to be paid collectively from the general budget of the government[3].

Roughly speaking, there are two arguments around the choice of a mode and of an institution for spectrum assignment. One argument recommends to introduce market mechanism for the reason that it can promote efficient use of spectrum resources.[4] The other argument insists introduction of commons by emphasizing the advantage of spectrum sharing

[3] FCC [2004] has introduced *private commons*, in which an exclusive user of spectrum offers a block to its customers for commons use.

[4] See Coase [1959] and Kwerel and Williams [2002], among others.

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

accomplished by recent technological progress.[5] Observe that the two arguments are not mutually exclusive; in fact, it is possible to let an assignment under market mechanism and an assignment with commons coexist side by side and compete each other, provided that spectrum bands can be supplied for these uses . The problem lies in the shortage of spectrum bands which can be allocated and assigned to new uses under market mechanism or with commons.

E. The Objective of this paper

Thus, until recently, the principle of government control prevailed in spectrum utilization. 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.

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 reallocation or reassignment of radio spectrum between incumbent and new users is unavoidable. Needless to say, there will be a strong opposition to such 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. Further, 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.

In the following section, Section II, the system of modified lease auction (MLA) will be

---

[5] See Baran [1995], Benkler [1998], Gilder [1994], and Ikeda [2002].

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

introduced. It is noted that MLA can accommodate various modes of spectrum utilization such as exclusive use, shared use, and commons use. In Section III, 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.

II Spectrum Assignment by means of Lease Auction (MLA)

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 current 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 current system to MLA. We need a scheme for gradual transition, which will be presented in the following section, Section III. 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.

B. Simple lease auction (LA)

Let us first define *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 license restrictions.

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. Club or commons use can be realized by the government through allocation 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 club or commons mode. A

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

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.

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 club 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 such users. If 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 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 good signal for spectrum reallocation. The other advantage is that it gives an incentive to save spectrum use.

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 timewise, frequency-wise, 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. UWB 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

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

to UWB uses. The lease price for this is to be paid from the general tax so that, in effect, the 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 also designated to be of commons 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.

C. 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-controlled 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 in 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).

Two categories of ROD may be distinguished. The first category 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.

The second category of ROD arises from a decision by the government to reallocate a

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

spectrum band. 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. We will not deal with this category of risk in this paper[6].

D. Protecting incumbents from ROD

In order to protect incumbents from ROD of the first category, 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 and 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 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, in effect, is a combination of (a) and (b) above, since this would favor 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 ROD. This may be a

[6] See Oniki [2004], which proposed a system for spectrum reallocation and considers the issue of risk arising from it.

possible research subject in the future.

E. Further considerations of ROD

Let us consider here economic meanings of ROD, including ROD of the first category and ROD of the second category. ROD arises when the spectrum user is forced to give up using spectrum bands/blocks because of a decision made by other spectrum users or by the government. 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.

<*** Figure 2 here ***>

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 exhibit, as other space resources do, 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, 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 receivers.

Note that the range of spectrum bands/blocks which exhibit significant positive

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

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 with a contract which is far from optimum. To avoid costs arising from hold-up cases, we prefer MLA to the property system.

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.

III Gradual Transition from the Current System to 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 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

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

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 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 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.

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,

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

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.

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 once the execution period starts. 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

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

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.

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 reject 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.

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 does, 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

$0 \leqq d(t) \leqq 1$ for $0 \leqq t \leqq T$; $d(t) = 0$ for $t > T$.

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

$d(t)=(T- t)/T$, for $t \leqq T$, and $d(t)=0$, 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

$0 \leqq AAC(t) \leqq BAP(t)$, 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

oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

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 proposed here is independent of the non-distributive 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 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 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.

References

Baran, P. [1995], “Is the UHF Frequency Shortage a Self Made Problem?” *Speech at the Marconi Centennial Symposium*, Belogna, Iraly, June 23, 1995. http://wireless.oldcolo.com/course /baran2.txt (as seen on December 27, 2001).

Benkler, Y. [1998], “Overcoming Agoraphobia,” *Harvard Journal of Law and Technology*, vol.11, 1998. http://www.law.nyu.edu/benklery/agoraphobia.pdf (as seen on December 27, 2001).

Cave, M. [2002], *Review of Radio Spectrum Management, An independent review for Department of Trade and Industry and HM Treasury*, March 2002. http://www.spectrumreview.

radio.gov.uk (as seen on October 12, 2002).

Coase, R. H. [1959], “The Federal Communications Commissions,” *The Journal of Law and Economics*, vol. II, 10, 1959.

Cramton, P, E. Kwerel, and J. Williams [1998], “Efficient Relocation of Spectrum Incumbents” *The Journal of Law and Economics*, Vol. 41, pp. 647-675.

Faulhaber, Gerald R. and David Farber [2002], *Spectrum Management: Property Rights*, Markets, and the Common, April 17, 2002. http://bpp.wharton.upenn.edu/Acrobat/ Faulhaber_AEW_paper_6_19_02.pdf (as seen on October 26, 2002).

Federal Communications Commission [2003], "Report and Order and Further Notice of Proposed Rulemaking in the Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets," October 6, 2003. (http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-113A1.pdf)

Federal Communications Commission [2004],"Second Report and Order, Order on Reconsideration, and Second Further Notice of Proposed Rulemaking in the Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets," September 2, 2004.
(http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-04-167A1.pdf)

Federal Communications Commission, Spectrum Policy Task Force, [2002], *Spectrum Rights and Responsibilities*, August 9, 2002. http://www.fcc.gov/sptf/files/0809fcc.pdf (as seen on October 12, 2002).

Gilder, George [1994], “Auctioning the Airwaves,” *Forbes*, April 11, 1994. http://www.seas.upenn.edu/~gaj1/auctngg.html (as seen on December 27, 2001).

Hazlett, Thomas W. [1998], “Assigning Property Rights to Radio Spectrum Users: Why Did FCC License Auctions Take 67 Years?” *Journal of Law and Economics*, Chicago: University of Chicago Press, October 1998, pp.529-576.

Ikeda, N. [2002], "The Spectrum as Commons: Digital Wireless Technologies and the Radio Policy," *RIETI Discussion Paper Series*, October 2002. http://www.rieti.go.jp/jp/publications/ summary/02030001.html (as seen on October 26, 2002).

Ikeda, Nobuo and Lixin Ye [2003], "Spectrum Buyouts: A Mechanism to Open Spectrum," *RIETI Discussion Paper Series*, December 2003.
(http://www.rieti.go.jp/jp/publications/summary/02030001.html).

Kwerel, Evan and John Williams [2002], "A Proposal for a Rapid Transition to Market Allocation of Spectrum," *OPP Working Paper Series*, No.38, Federal Communications Commission, Office of Plans and Policy, pp.1-54.
(http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228552A1.pdf).

Mas-Colell, Andreu, Michael D. Whinston, and Jerry R. Green, *Microeconomics Theory*, Oxford: Oxford University Press, 1995.

Noam, Eli M. [1998], "Spectrum Auctions: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism.　Taking the Next Step to Open Spectrum Access," *Journal of Law and Economics*, Chicago: University of Chicago Press, October 1998, pp.765-790.

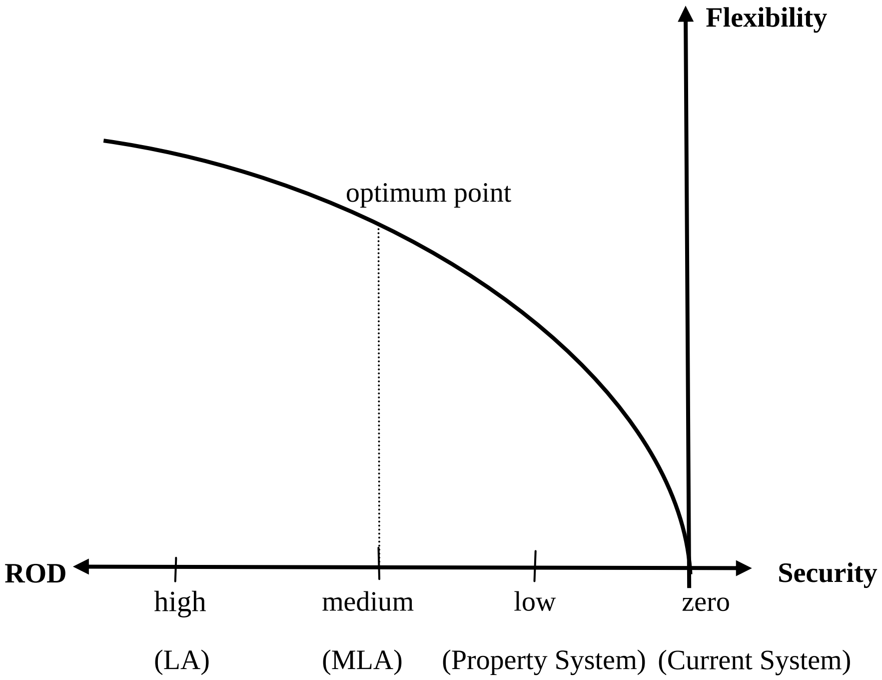
Oniki, H. [2004] "Reallocation of Radiowave Spectrum with a Price Mechanism: Proposal of a System of Insurance and Compensation," Paper presented at the 32nd Research Conference on Communication, Information and Internet Policy (Telecommunications Policy Research Conference 2004) held at the Tech Center, George Mason University, U.S.A, October 1-3, 2004. An earlier version of the paper was presented at SNU Center for Law & Technology's 2004 International Symposium in Seoul: Beyond Property v. Commons Dimension for a New Spectrum Management System, held in Seoul, Korea August 16, 2004.
(http://www.osaka-gu.ac.jp/php/oniki/noframe/eng/publication/200408a.html)

Figure 1: Example of Spectrum Usage -- Allocation and Assignment 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
Allocation	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)	Club	Commons (UWB)	Commons	Commons ("unlicensed")
Assignment	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									

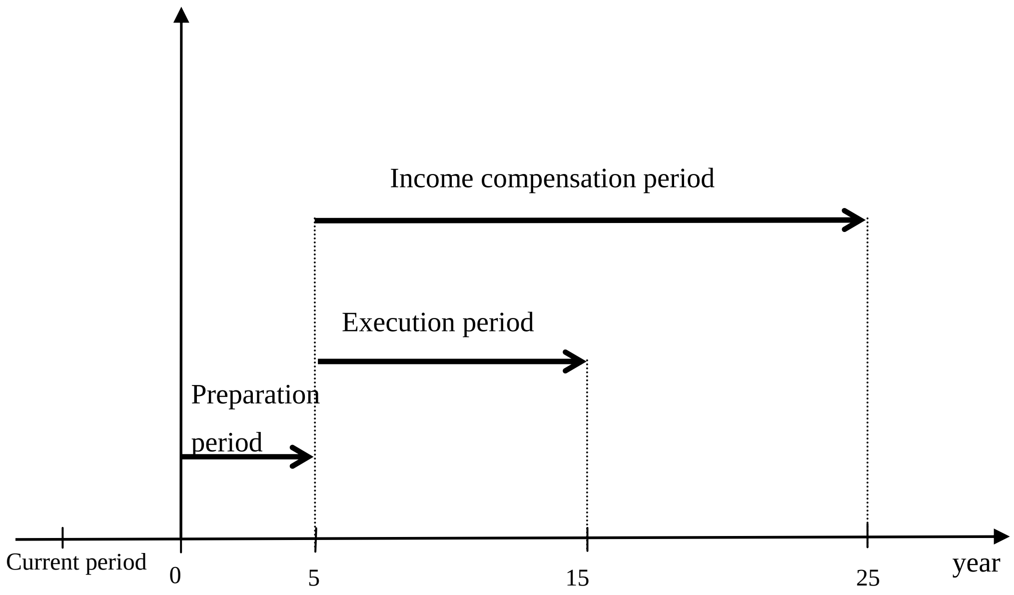
oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

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



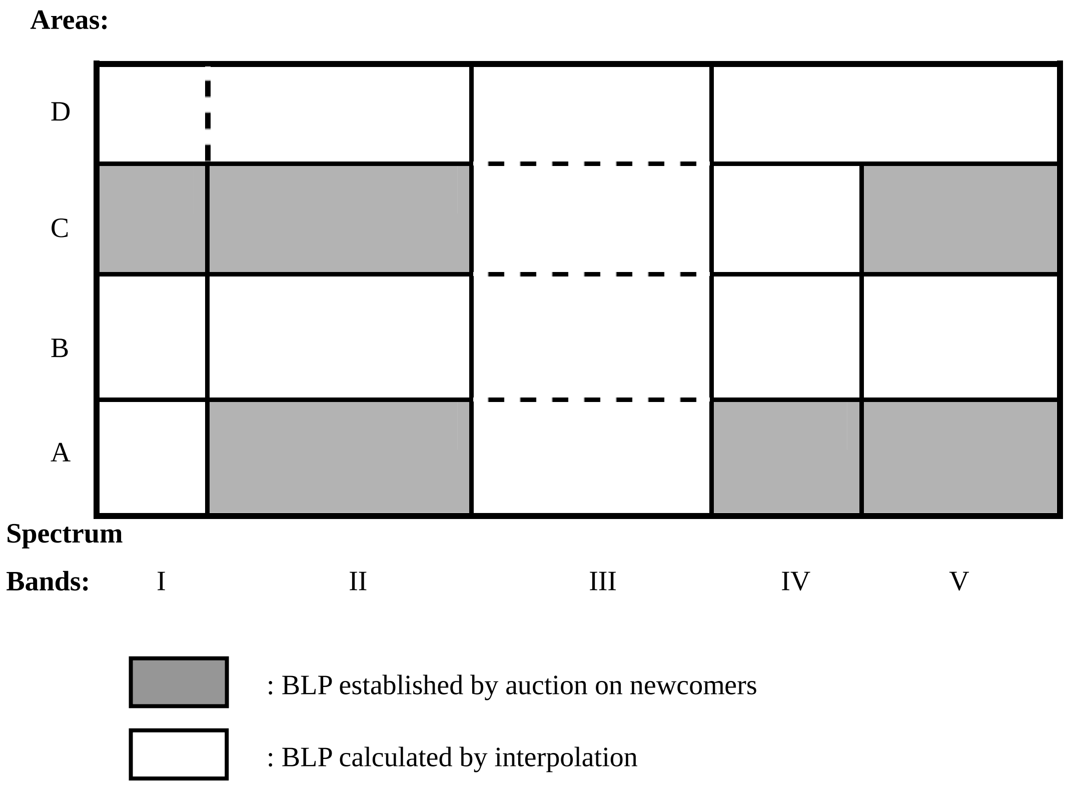
oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

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



oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/

Figure 4. Establishing “benchmark lease prices (BLP)”



oniki@alum.mit.edu
www.osaka-gu.ac.jp/php/oniki/