"Allocation and Assignment of Radio-Spectrum Resources by using Price Mechanism: Proposals for a New System"

WORKSHOP on Advanced Wireless Technologies:
Implications for Spectrum Management
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I. Introduction and Background

A. History of spectrum use: technological progress

1. Early 20-th century
   used for maritime navigation
   navy operations
2. 1920's
   voice-radio broadcasting
3. 1930-40's
   military use, radars

A. History of spectrum use: technological progress

4. 1950's
   television broadcasting, FM radio
5. 1960's〜present
   many applications including mobile telephony,
   wireless Internet, etc.

B. Administration of spectrum resources

1. Command and control by country government ("socialist system")
   a. introduction of new technology to expand the frontier of spectrum use
   b. assignment of new spectrum blocks to users with zero usage price
   c. prevention of interferences

B. Administration of spectrum resources

2. Allocation and assignment of spectrum
   a. spectrum allocation by

      international organizations (ITU, EC)

      country government

   b. spectrum assignment (licensing) by country government zero price to users

C. Emergence of spectrum shortage

1. End of spectrum-frontier expansion
   no more spectrum band of “good quality”
   upper limit: 3-5 GHz

C. Emergence of spectrum shortage

2. Attempts to use price mechanism in assigning spectrum blocks
   a. new licensing on auctions (US: 1993～, EU: 2000 for G3, etc.)
   b. spectrum usage fees

C. Emergence of spectrum shortage

2. Attempts to use price mechanism in assigning spectrum blocks

c. problems:

spectrum “bubbles” (high price)
spectrum may become a private property
spectrum fees may be only nominal

C. Emergence of spectrum shortage

3. Attempts to re-allocate/re-assign spectrum bands

a. international negotiations

b. re-allocation by country government
Japan (2003～ for wireless LAN)
by command and control

C. Emergence of spectrum shortage

3. Attempts to re-allocate/re-assign spectrum bands

c. problems:

slow and costly negotiations
creates risk and uncertainty to incumbents
generates regulatory complexities
extreme inefficiencies continue to remain

C. Emergence of spectrum shortage

4. Emergence of new technologies

a. possibility of "spectrum commons"

spread spectrum, underlay, UWB, software radio

C. Emergence of spectrum shortage

4. Emergence of new technologies

   b. observation:

   significant increase in spectrum capacity

   new technologies are created for using "unlicensed bands"

   proposals of open use to replace licensing (*"commons" campaign*)

II. Present System of Spectrum Utilization

A. Spectrum as an economic resource

B. Allocation of spectrum bands (ALLOC)

C. Assignment of spectrum blocks (ASSGN)

D. The challenge in the age of spectrum shortage

A. Spectrum as an economic resource

1. One of space resources
   a. physical spaces:
      land, water surface, aviation space,
      satellite orbits, etc.
   b. electromagnetic spaces:
      radio spectrum, optical spectrum.

A. Spectrum as an economic resource

2. Non-reproducible natural resource
   a. does not deplete
      (unlike mineral, oil deposits)
   b. does not depreciate
      (unlike machines, equipment)

A. Spectrum as an economic resource

3. Physical capacity limit boundary and size
4. Technology and capital for using spectrum
   a. technological progress leads to capacity increase
   b. substitution between capital and spectrum size

A. Spectrum as an economic resource

5. Modes of utilization
   a. Exclusive use
   b. Club use
   c. Commons use

A. Spectrum as an economic resource

6. Positive externalities
   scale economy

7. Negative externalities
   interferences, congestions

8. Illustration <Figure 1>

B. Allocation of spectrum bands (ALLOC)

1. Outline
   a. *zoning* of spectrum
   b. two-level system:
      country and international
   c. no price mechanism is used
      command and control
      direct negotiations

B. Allocation of spectrum bands (ALLOC)

2. Items to be specified

a. objective

b. priority

c. usage mode
   exclusive, club, commons
   (unlicensed, open use)

d. technical items

B. Allocation of spectrum bands (ALLOC)

3. Two-level specification

a. international level
   negotiations in ITU, EC

b. country level
   command and control (beauty contest)

B. Allocation of spectrum bands (ALLOC)

4. Re-allocation
   a. by international negotiations
   b. with insurance-compensation system* (IV)

B. Allocation of spectrum bands (ALLOC)

5. Problems-----difficulties in re-allocation
   a. international negotiations are difficult
   b. negotiation with incumbents are difficult
6. Illustration <Figure 2>

C. Assignment of spectrum blocks (ASSGN)

1. Outline

a. specification of actual user(s) of spectrum blocks licensing

b. executed by country government

C. Assignment of spectrum blocks (ASSGN)

2. Items to be specified to users

a. spectrum blocks

b. duration of license

c. priority, time of use

d. emission power, technical items

C. Assignment of spectrum blocks (ASSGN)

3. Exclusive use----alternative systems for ASSGN

a. Traditional system
- assignment by country government
  - comparative hearings (beauty contest)
  - lotteries
- zero or nominal rent
- automatic (or likely) renewal of license at expiration

C. Assignment of spectrum blocks (ASSGN)

3. Exclusive use----alternative systems for ASSGN

b. Private-property (or semi-private property) system
- assignment with auction
- competitive price paid in one installment
- automatic (or likely) renewal

C. Assignment of spectrum blocks (ASSGN)

3. Exclusive use----alternative systems for ASSGN

c. Competitive lease system *(V.)

assignment by country government with auction on lease price

competitive lease price paid

re-assignment with auction at expiration

no automatic renewal

modifications in favor of incumbents

C. Assignment of spectrum blocks (ASSGN)

4. Club use

a. Traditional system

licensing by country government

unlimited entry

zero or nominal rent

automatic renewal

examples: amateur wireless, navigation, aviation

b. *privatized* club use *(III.)

C. Assignment of spectrum blocks (ASSGN)

5. Commons-----open use

a. traditional system
   no licensing
   power limit

b. commons as a public good *(III.)

C. Assignment of spectrum blocks (ASSGN)

6. Problems

a. Exclusive use under traditional system
   low-efficiency uses continue to remain
   new entry is difficult
   competition is precluded
   no incentive to save spectrum
   low incentive for technological progress

C. Assignment of spectrum blocks (ASSGN)

6. Problems

b. Exclusive use under private-property system

"spectrum hold-up" may occur

C. Assignment of spectrum blocks (ASSGN)

6. Problems

c. Club use under traditional system

congestion may occur

re-assignment (re-allocation) is difficult because of the involvement by many users

C. Assignment of spectrum blocks (ASSGN)

6. Problems

d. Commons under traditional system
re-assignment (re-allocation) is difficult
because of the involvement by many users

7. Illustration <Figure 2>

D. The challenge in the age of spectrum shortage

1. Present state

incumbent users with vested interests

free and continuing use

2. Need for re-allocation

emergence of new objectives for spectrum use

D. The challenge in the age of spectrum shortage

3. **Need for re-assignment**
   new users, new business
4. **Need for accommodating new technologies**
   for spectrum sharing
5. ***The challenge***
   gradual but steady improvement

III. Provision for Spectrum Commons as a Public Good (A Proposal)

A. Outline

B. Proposals *

A. Outline

1. Technology for spectrum sharing
   a. to increase efficiency and flexibility by sharing a spectrum block with many users
   b. new technology
      SS, CDMA, underlay, UWB

A. Outline

1. Technology for spectrum sharing
   c. *old technology*
      amateur wireless, navigation use, aviation use
   d. commons for using land space
      public parks, street roads, town commons

A. Outline

2. Outcome from using commons:

   a. depends on demand (number of users) and supply (capacity of spectrum block)

   b. efficient use with *ample capacity*

   c. congestion with *capacity shortage*

   d. outcome may change in the long run from free use to congestion

A. Outline

3. Observation

   a. spectrum sharing under direct governmental control (Mode-G)
   commons: ISM
   clubs: navigation and aviation, outdoor wireless-LAN

A. Outline

3. Observation

b. Spectrum sharing under private licensee's control (Mode-L)

commons:

free broadcast to viewers

clubs: mobile telephony, pay-per-view broadcast

A. Outline

3. Observation

c. mode-G commons may lead to congestion and inefficient use, but re-allocation is difficult

need for creating a system with easy re-allocation

B. Proposals*

1. Preference of Mode-L to Mode-G for spectrum sharing
   a. strong incentives for efficient use
   b. convenience for re-allocation and re-assignment

B. Proposals*

2. Mode-L spectrum sharing
   a. assign spectrum blocks exclusively to private licensees
   b. let the licensees supply spectrum blocks to end users in club or commons
   c. examples
      outdoor wireless LAN

B. Proposals*

3. Mode-G spectrum sharing (spectrum as a *public good*)

a. establish a *public agent* to administer Mode-G spectrum clubs or commons

to avoid formation of unlimited rights

of using spectrum

B. Proposals*

3. Mode-G spectrum sharing (spectrum as a *public good*)

b. let the *public agent* supply spectrum blocks to end users in clubs or commons the cost for the agent to secure the blocks may be paid from government budget (along with paying for other public goods) (V.)

B. Proposals*

3. Mode-G spectrum sharing (spectrum as a public good)

b. let the public agent supply spectrum blocks to end users in clubs or commons
the agent administers insurance-
compensation for re-allocation* (IV.)
Mode-G commons become a *public good*

B. Proposals*

3.Mode-G spectrum sharing (spectrum as a public good)

c. examples (over direct termination of license):
ISM, indoor wireless LAN

d. advantages:
reveal the opportunity cost of spectrum bands/blocks supplied as a public good
create a representative of users' interests
re-allocation, re-assignment will be easier

B. Proposals*

3. Mode-G spectrum sharing (spectrum as a public good)

e. observation on Mode-G commons
would be the same as present-day unlicensed blocks if operated under government command and control
would become a free good if spectrum capacity exceeds demand because of technological progress
but otherwise would turn to a public goods

B. Proposals*

4. Illustration <Figure 3>

IV. Re-allocation of Spectrum Bands with Compensation -------An Insurance-Compensation System with Proper Incentives

A. Outline

B. Insurance-compensation system for re-allocation within a country* (a proposal)

C. International insurance-compensation system for spectrum re-allocation* (a proposal)

A. Outline

1. Re-allocation of spectrum bands
   a. need arises from technological progress and changes in demand
   b. shortage of spectrum bands to meet new demand
   c. shortage is a global (frequency-wise) problem over all spectrum bands

A. Outline

1. Re-allocation of spectrum bands
   d. re-allocation is to be made locally with a single band
   e. a band to be re-allocated is a “sacrifice” for the benefit of other users
   f. need for compensation to outgoing users at re-allocation, the cost should be paid by all users

A. Outline

2. Compensation

a. *acceptable compensation*
   the least amount of money for which a spectrum user to accept termination of using a block; the user moves from current activity X to new activity Y accordingly.

A. Outline

2. Compensation

b. determination:

(acceptable compensation)

= (present value of activity X)

−(present value of activity Y) + Q

Q = once-and-for-all cost of moving from X to Y

A. Outline

2. Compensation

c. compensation would be needed regardless of the system of assignment:

command and control, property system, competitive lease, Mode-L or Mode-G commons / clubs.

A. Outline

2. Compensation

d. compensation in kind under command and control:
part of compensation is made in the form of providing spectrum at some band:
acceptable compensation need to be declared for each specification of compensation in kind.
example:
X = 1MHz in the 2GHz band
Y = 2MGz in the 15GHz band

B. Insurance-compensation system for re-allocation within a country (a proposal)

1. Acceptable compensation and premium

a. acceptable compensation to be declared by each spectrum user

B. Insurance-compensation system for re-allocation within a country (a proposal)

1. Acceptable compensation and premium

   b. annual compensation premium to be paid by each spectrum user annually to spectrum manager (country government)
   = (declared acceptable compensation) times (premium rate)

B. Insurance-compensation system for re-allocation within a country (a proposal)

2. Premium rate and government budget

   a. premium rate
   to be determined by spectrum manager so that the total annual income from the compensation premiums be equal to the total annual compensations paid for the re-allocation in the year.

B. Insurance-compensation system for re-allocation within a country (a proposal)

2. Premium rate and government budget

b. implications

actuarially fair insurance

balanced budget for spectrum re-allocation

B. Insurance-compensation system for re-allocation within a country (a proposal)

3. Determination of spectrum bands to be re-allocated

a. indicator of efficiency increase from re-allocating a band: = (B−C) / A, where

A = (present value of using the band under old objective)

B = (present value of using the band under new objective)

C = (amount of compensation for the re-allocation)

B. Insurance-compensation system for re-allocation within a country (a proposal)

3. Determination of spectrum bands to be re-allocated

b. maximum efficiency indicator
the band with the highest efficiency indicator (which exceeds 1) is to be chosen for re-allocation
an incentive for honest declaration of acceptable compensation by users

B. Insurance-compensation system for re-allocation within a country (a proposal)

4. Determination of data A and B for re-allocation

a. under command and control
country government needs to estimate both A and B

B. Insurance-compensation system for re-allocation within a country (a proposal)

4. Determination of data A and B for re-allocation

b. under property system

A and B may be obtained from appropriate market transactions if such take place, otherwise country government needs to estimate them.

B. Insurance-compensation system for re-allocation within a country (a proposal)

4. Determination of data A and B for re-allocation

c. under competitive lease

A can be calculated from current lease price, B can be calculated if there is a block being used for the new objective, otherwise it need to be estimated.

B. Insurance-compensation system for re-allocation within a country (a proposal)

5. Illustration <Figure 4>

C. International insurance-compensation system for spectrum re-allocation (a proposal)

1. Group of country governments for international insurance-compensation system (GIIC)
   a. to be formed voluntarily by country governments
   b. objectives:
      to administer international insurance-compensation for re-allocation to reveal information of the supply price of spectrum bands via compensation

C. International insurance-compensation system for spectrum re-allocation (a proposal)

2. Acceptable compensation and premium

a. to be declared by each member country for each band

b. annual compensation premium to be paid by each member country annually to GIIC
= (declared acceptable compensation) times (premium rate).

C. International insurance-compensation system for spectrum re-allocation (a proposal)

3. Premium rate and determination/recommendation of spectrum bands to be re-allocated internationally

a. premium rate
to be determined by GIIC so as to balance its annual budget

b. indicator of efficiency increase from re-allocating a band internationally
(same as in V.B.3.a)

C. International insurance-compensation system for spectrum re-allocation (a proposal)

3. Premium rate and determination/recommendation of spectrum bands to be re-allocated internationally

c. maximum efficiency increase the band with the highest efficiency indicator (which exceeds 1) is to be chosen for re-allocation

C. International insurance-compensation system for spectrum re-allocation (a proposal)

3. Premium rate and determination/recommendation of spectrum bands to be re-allocated internationally

d. GIIC
executes or recommends (to ITU, EC) the choice of the band (in c. above)
pays compensation to each member country according to re-allocation agreement made in ITU, EU.

C. International insurance-compensation system for spectrum re-allocation (a proposal)

4. Behavior of a member country of GIIC

a. member country with a domestic insurance-compensation system operates with two *accounts*:

C. International insurance-compensation system for spectrum re-allocation (a proposal)

4. Behavior of a member country of GIIC

with GIIC system:

- **represents GIIC to domestic users as a (neutral) intermediary**
- **domestic users deal in effect directly with GIIC**
- **decreases incentive for dishonest declaration of acceptable compensation by users**

C. International insurance-compensation system for spectrum re-allocation (a proposal)

4. Behavior of a member country of GIIC

with domestic insurance-compensation system for domestic re-allocations:

users pay annual premium both to GIIC and domestic government

domestic budget will be balanced

C. International insurance-compensation system for spectrum re-allocation (a proposal)

4.Behavior of a member country of GIIC

b. member country without a domestic insurance-compensation system

needs to estimate acceptable compensation for each band

budget from paying premiums and receiving compensations need not balance

C. International insurance-compensation system for spectrum re-allocation (a proposal)

5. Illustration <Figure 5>

V. Re-assignment of Spectrum Blocks ------ Modified Lease Auction (MLA)

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

B. Accommodation of various usage modes within the system of LA

V. Re-assignment of Spectrum Blocks
------ Modified Lease Auction (MLA)

C. Disadvantages of LA

D. Protecting incumbents against ROD to an appropriate degree

E. Further consideration of ROD

F. Remarks

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

1. Spectrum resources owned by government and leased to spectrum users (managers), private or public, by auction; lease to be applied to all users including government users ----- no exception

   give incentive to save spectrum use

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

2. Auction for each spectrum block --- frequency range, geographical area, time, priority
3. Resale of licenses ----- permitted within ALLOC and AGGGN specifications

B. Accommodation of various usage modes within the system of LA

1. Exclusive use:

   winner of auction become the user

2. Club use:

   winner of auction represent the share users

B. Accommodation of various usage modes within the system of LA

3. Commons use:

a. type-1 ("unlicensed" use)

winner of auction of primary exclusive right become the manager of the union of, e.g., suppliers of devices using the spectrum; union membership should be open and members pay the lease prices

B. Accommodation of various usage modes within the system of LA

3. Commons use:

b. type-2 ("overlay" including UWB)

winner of auction of secondary right become the manager of the union of suppliers of devices, etc.

B. Accommodation of various usage modes within the system of LA

4. Government may support commons use

   government agent may bid and win auction;

   the lease price is paid by government;

   an upper limit of lease price is specified prior to auction

C. Disadvantages of LA

1. Risk of lease discontinuation (ROD) to spectrum users

   arising from newcomers outbidding incumbents

2. Cost of administering auctions

D. Protecting incumbents against ROD to an appropriate degree

1. Against ROD :

   a. discount of lease price to incumbents

   b. auction to be held years before the beginning of license period

D. Protecting incumbents against ROD to an appropriate degree

1. Against ROD :

   c. use of “pre-auction” (winners obtain discount)

   d. creation of futures and options markets for leasing spectrum

E. Further consideration of ROD

1. Economic meaning of ROD

a. the other side of economic growth

b. a price of having flexibility in spectrum use

c. no ROD in stationary (stagnant) economy

E. Further consideration of ROD

2. The degree of ROD

a. determines the balance between the security to incumbents and the chance of entry by newcomers

b. optimum to be found by trials and errors

E. Further consideration of ROD

2. The degree of ROD

c. zero: allocation by central planning (assignment by government with automatic renewals)

low: auction on the right to use spectrum permanently

medium: MLA

high: LA

E. Further consideration of ROD

3. Illustration <Figure 6>

F. Remarks

1. Why not perpetuity (property ownership system) ?

a. presence of externalities (scale economies) in the use of spectrum

b. Coase's theorem does not work because of uncertainty and bargaining time/cost (for Nash equilibrium with different information sets)

F. Remarks

2. Why not LA? (why are the modifications needed?)

a. with incomplete and costly information, prevalence of ROD may not be optimal.

b. positive economics for determining "optimal degree of protection against ROD"?

--- a subject for future research.

VI. Gradual Transition to MLA

A. Overview

B. Transition

C. Income Compensation

D. Forecast

A. Overview

1. Need for gradual and informed transition

   a. cost of transition arising from the presence of capital stock and human skills fitted to the old system

   b. information about the overall transition process is needed for the formation of transition plan by spectrum users

A. Overview

2. policies for transition

a. formation of "benchmark lease price (BLP), a proxy of market price"

b. gradual increase in usage fees from the current level (=0) to the market price (=BLP)

c. provisions for income compensation

B. Transition

1. Preparation period (M years)

a. MLA to be applied to new assignments

zero usage fees to incumbents

b. BLP: to be set at auction prices if available, else to be calculated by interpolation-periodic revisions

B. Transition

2. Execution period (N years)

   a. MLA to new assignments

   b. partial lease price (PLP), equal to ((n/N)* BLP), to be paid by incumbents in n-th year (n=1,2,...,N); no ROD to incumbents

B. Transition

3. Completion of transition process

   a. traversing smoothly to full-scale MLA

   b. all licenses to be issued under MLA with payment of full lease price (FLP) thereafter

   c. resale of licenses permitted

4. Illustration <Figures 7, 8>

C. Income Compensation

1. Overview

   a. (possible) compensation to incumbents for the payment of PLP and FLP

   b. complete separation of spectrum usage and income distribution

C. Income Compensation

2. Determination of compensation

   a. compensation period : t=1,2,・・,T;no compensation for t > T

   b. base amount of payment (BAP): the value of the spectrum held at t=0 evaluated in terms of current PLP or FLP, whichever applied.

C. Income Compensation

c. the degree of compensation for period t, d(t);

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

$d(t) = 0$ for $t > T$.

d. linear sunset:

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

$d(t) = 0$ for $t > T$.

C. Income Compensation

3. Policies for compensation:

a. government determines g for each user category

near-full compensation: military and security users (g=1)

partial compensation : government users, public utilities, public

transportation operators, welfare agents, etc. (g=0.5)

no compensation : profit-seeking entities, individual users (g=0)

C. Income Compensation

3. Policies for compensation:

b. actual amount of compensation in period t : AAC(t)

$$AAC(t) = g*d(t)*BAP(t),$$

$$0 \leqq AAC(t) \leqq BAP(t), \quad t = 1,2,\ldots,T.$$

C. Income Compensation

4. Neutrality

choice of a degree of compensation d(t) does not affect the incentive to save and release spectrum by incumbents

D. Forecast

1. increase in lease price in the preparation period
   because of unbalanced usages still remaining
2. gradual decrease in the execution period and afterward
   because of “leveled” usage
3. lease price will approach to zero in the long run (?)
   depends technology and demand in the future

VII. Conclusion

Illustraion <Figure 9>