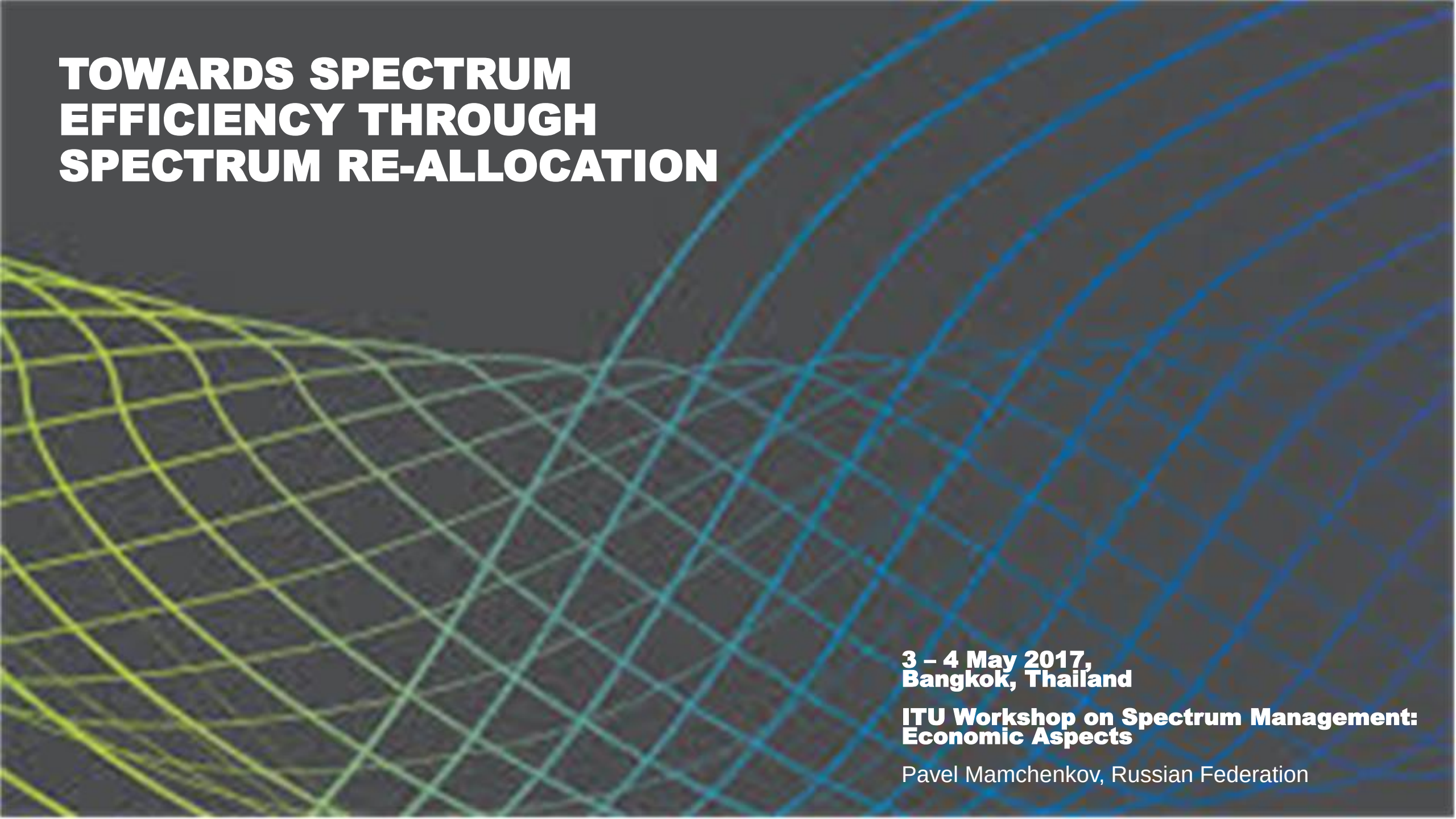
TOWARDS SPECTRUM EFFICIENCY THROUGH SPECTRUM RE-ALLOCATION



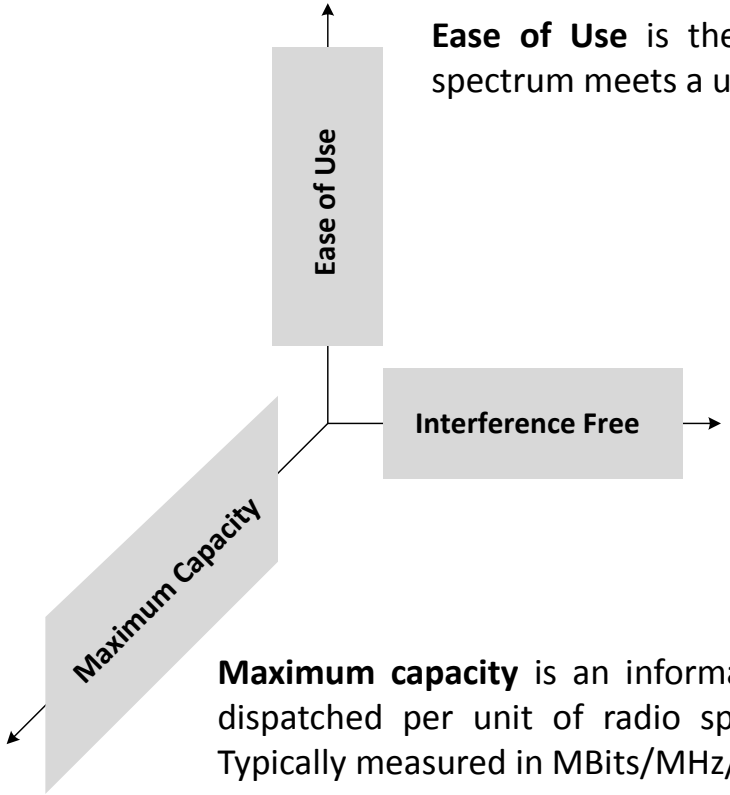
3 – 4 May 2017,
Bangkok, Thailand

ITU Workshop on Spectrum Management: Economic Aspects

Pavel Mamchenkov, Russian Federation

Two Components of Spectrum Efficiency

Technical Efficiency of Spectrum

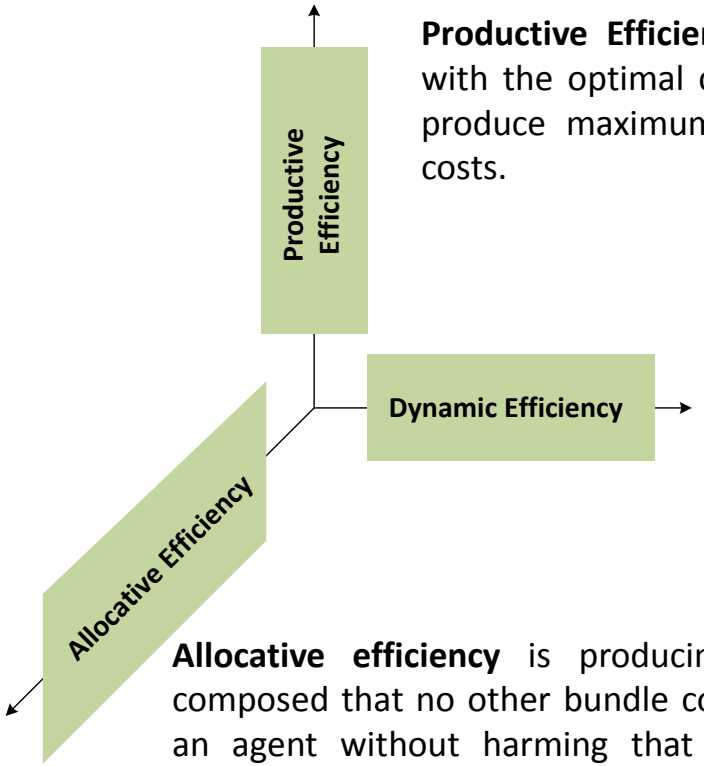


Ease of Use is the extent to which the use of spectrum meets a user's specific needs.

Interference free is an avoidance of critical degradation of quality of operation due to mutual influence of different emissions.

Maximum capacity is an information throughput that can be dispatched per unit of radio spectrum per unit of location. Typically measured in MBits/MHz/ km2

Economic Efficiency of Spectrum



Productive Efficiency is provision of services with the optimal combination of resources to produce maximum output for the minimum costs.

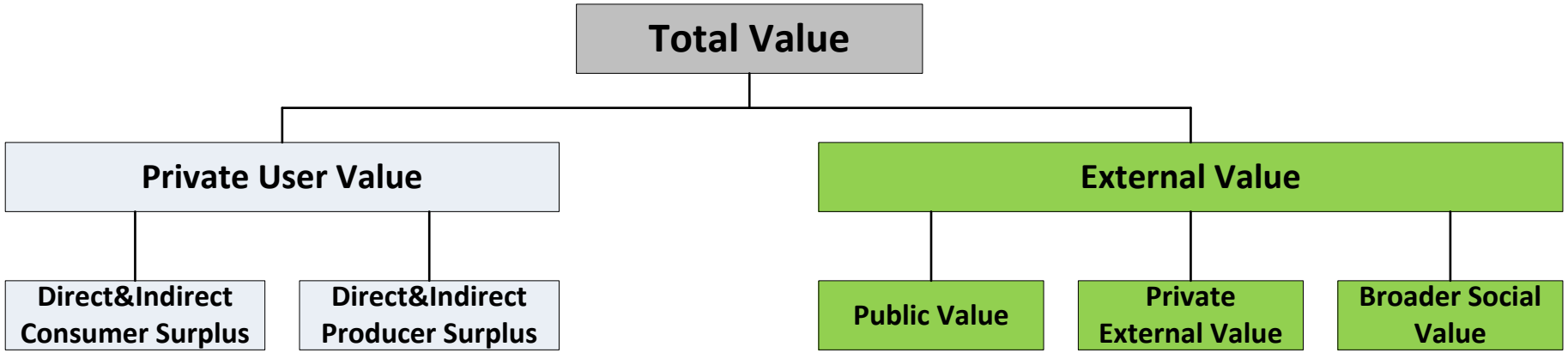
Dynamic efficiency is using the resource in a way enabling long-term productivity improvements through innovation and R&D.

Allocative efficiency is producing a bundle of services so composed that no other bundle could improve the well-being of an agent without harming that of another agent. Allocative efficiency relies on the Pareto criteria, that is, being able (or not) to improve the well-being of one economic agent without harming that of another.

Maximizing technical efficiency does not always maximizes total benefits from spectrum for the society

Pivotal Components of Spectrum Social Value

The value of spectrum for society is defined by benefits for consumers, producers and citizens from spectrum-utilizing services



Private User Value is the benefit to individuals from consumption of the services, less the costs of producing the services.

Private User Value is equal to the sum of consumer and producer surplus.

Direct benefits are benefits for service consumers and producers generate from the direct consumption and provision of radio services.

Indirect benefits are generated due to unintended effects of direct service on other product markets thus resulting in further indirect increase of producers and customers surplus.

External value is the additional benefits to society not reflected in the value of the service to consumers/producers.

Public value is the benefit that society derives from consuming public goods based on “non-excludability” and “non-rivalry” (such as defense).

Private External Value is the net private value to individuals that do not use services but are affected by positive or negative externalities.

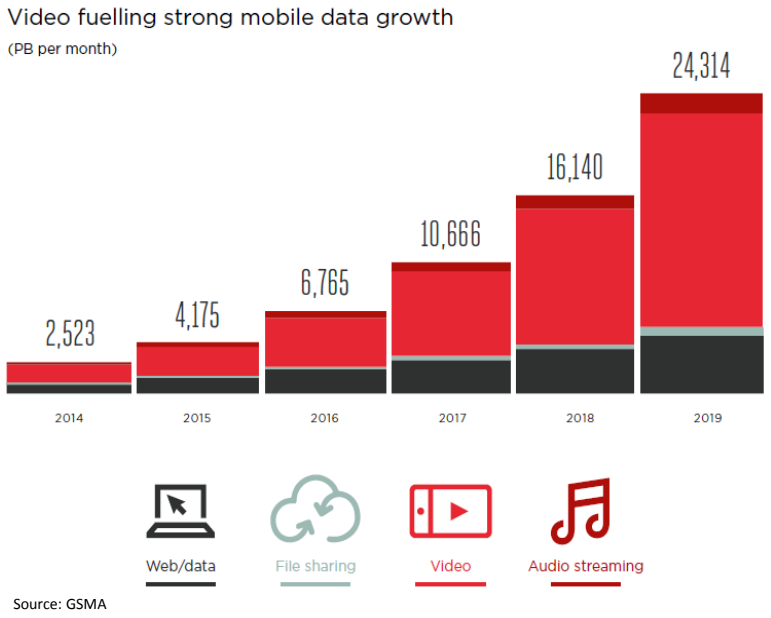
Broader Social Value is the benefit for citizens from the contribution of services to social goods incl. social capital, political freedoms, national culture, equality etc. irrespective of incomes.

Can be validly expressed in the monetary terms

Non-market valuation methods can be applied

The Footings of Spectrum Re-allocation

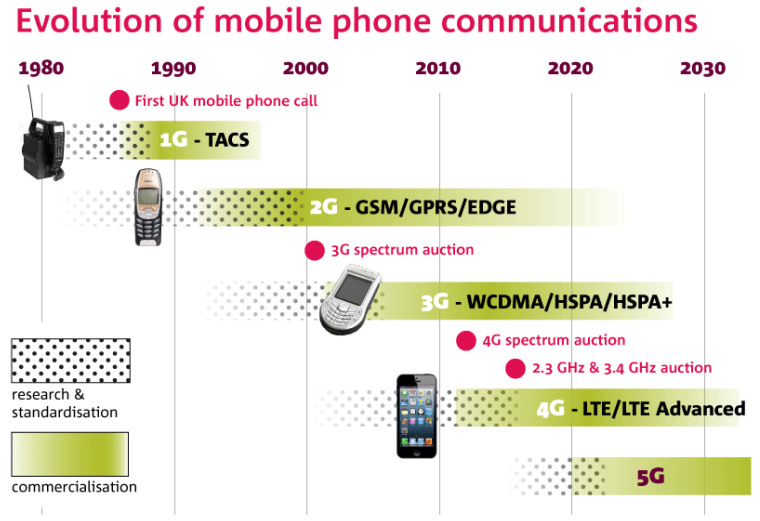
Towards the economy of gigabytes…



Source: GSMA

Demand for data is satisfied by faster growing radio technologies with greater geographic reach and capacity, advanced handsets with increased processing power, larger screens, ubiquitous applications such as social media, messaging, video streaming. Data traffic is growing exponentially 60% annually.

Turnover of radio technologies…



Source: Http://tutorvoice.com/index.php/2015/10/11/generations-of-wireless-communication-technology/

The pace of change in radio technologies is speeding up. From ten years life cycle of new generation in the past, now turnover is increasing. The advent of 4G LTE happened six/seven years from the mass commercial adoption of 3G. 5G is estimated to happen four/five years from adoption of 4G.

Revolving spectrum allocations…

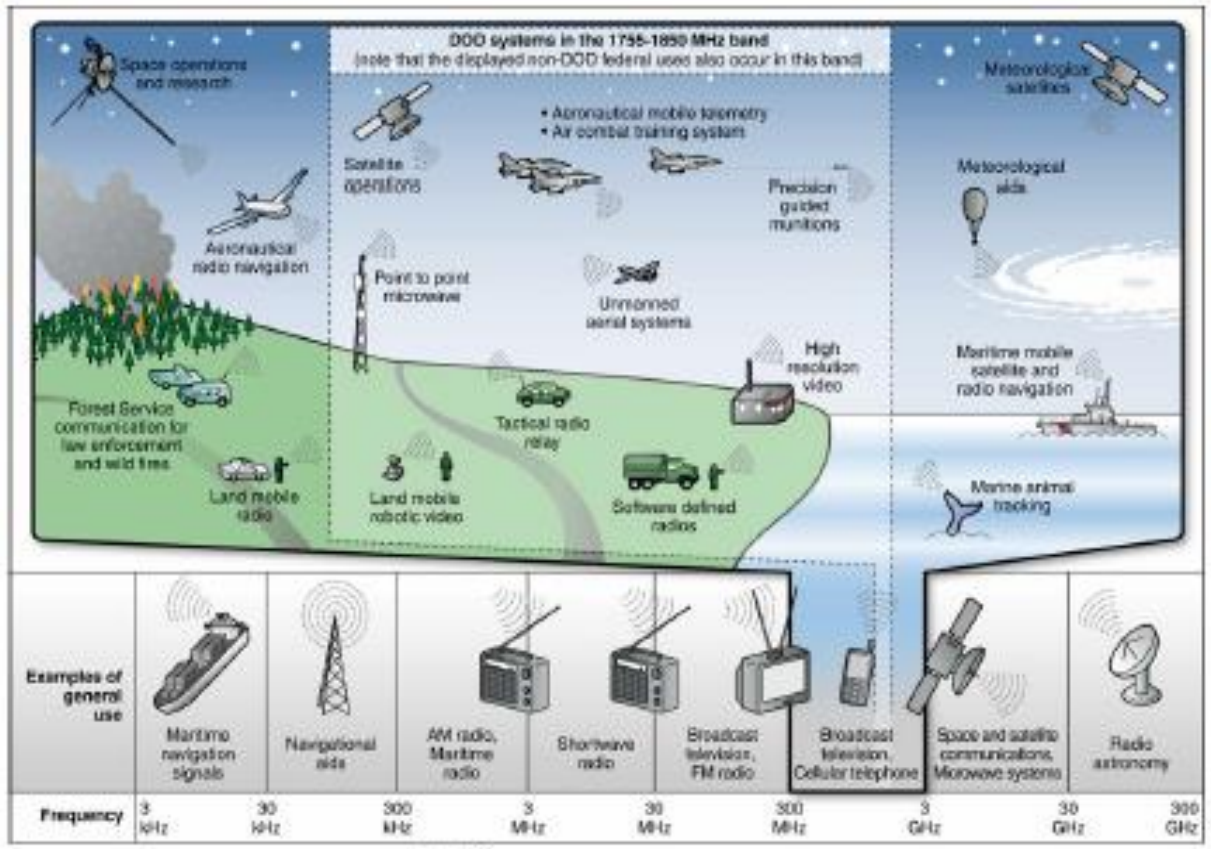
WRC-07 candidate bands	WRC-07 identified bands	WRC-15 Candidate bands	WRC-15 Identified bands
410 – 430 MHz	450 – 470 MHz	470 – 698 MHz	694 – 790 MHz
450 – 470 MHz	698 - 806 MHz	1350 – 1400 MHz	1427 – 1518 MHz
470 – 862 MHz	790 – 862 MHz	1427 – 1452 MHz	3300 – 3700 MHz
2300 – 2400 MHz	2300 – 2400 MHz	1452 – 1492 MHz	4800 – 4990 MHz
2700 – 2900 MHz	3400 – 3600 MHz	1492 – 1518 MHz	
3400 – 3600 MHz		1518 – 1525 MHz	
3600 – 3800 MHz		1695 – 1710 MHz	
3800 – 4200 MHz		2700 – 2900 MHz	
4400 – 4990 MHz		3300 – 3400 MHz	
		3600 – 3700 MHz	
		3700 – 3800 MHz	
		3800 – 4200 MHz	
		4400 – 4500 MHz	
		4500 – 4800MHz	
		4800 – 4990 MHz	
		5350 – 5470 MHz	
		5725 – 5850 MHz	
		5925 – 6425 MHz	

ITU is in the pervasive rush of seeking for new allocations for emerging radio technologies.

Effectively each WRC adopts a host of new spectrum bands for developing and emerging advanced radio technologies.

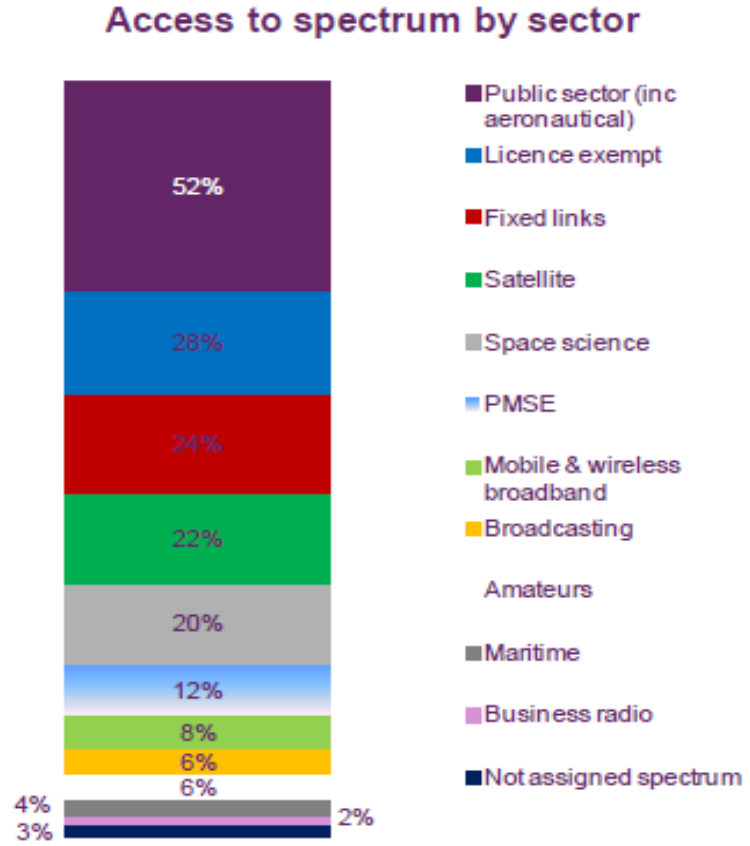
Today Spectrum Demand Exceeds Available Supply

Spectrum is a finite resource of great significance…



Souce: GAO. Spectrum Management. Federal Relocation Costs and Auction Revenues

Typical allocation between uses (UK case)…

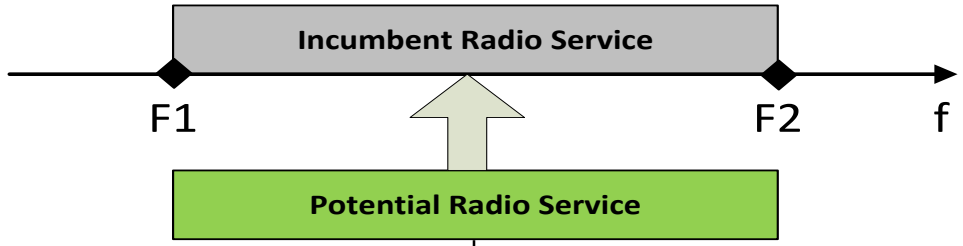


Source: OFCOM

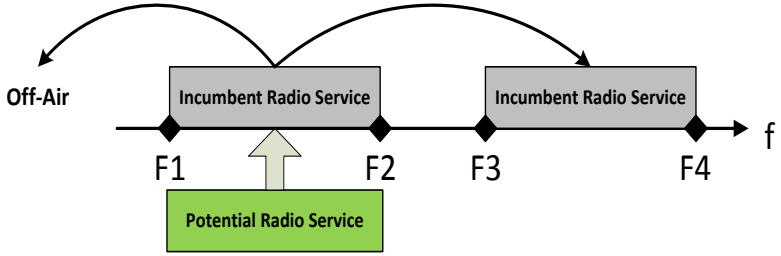
Balancing competing government and industry demands for a limited amount of spectrum, today and in future, is a challenging and complex task for each Telecommunications Administration

Methods to Achieve Spectrum Turnover

Target Setting

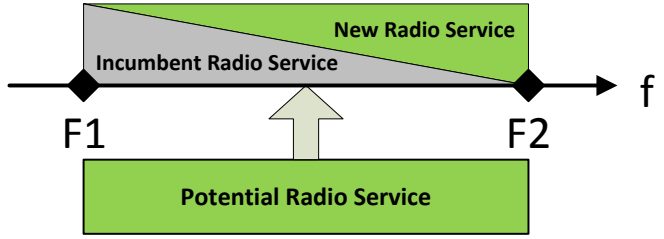


Spectrum Re-allocation



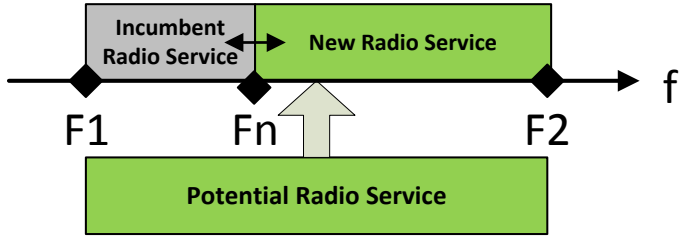
- Determination of alternative band for incumbent service.
- Determination of alternative off-air technology.
- Compensation for redeployment.
- Reallocation fund.

Spectrum Sharing



- Is sharing technically feasible?
- What are the technical constraints of sharing both for incumbent and potential radio services?
- For how long both services are able to coexist in the same band?

Spectrum Band Subdivision



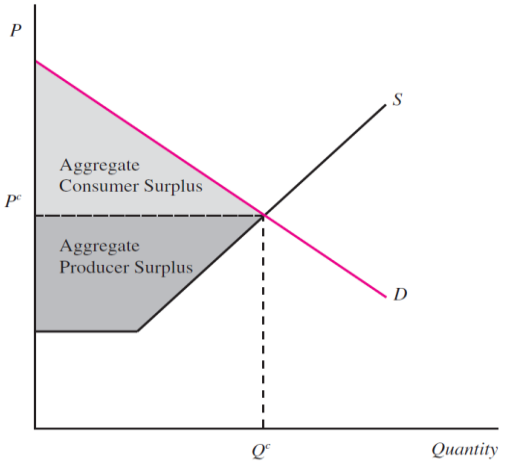
- Assessment of spectrum efficiency of the incumbent service.
- Inventory and frequency plan optimization of incumbent service.
- Assessment of total spectrum value for both incumbent and potential services.
- Finding optimal proportion of sub-bands.

Spectrum Re-allocation. Estimation of Total Value Components

Total Value

- **Private User Value**
- **External Value**

Can be validly expressed in the monetary terms



Total Surplus in a Competitive Market
Source: Church and Ware (2000)

Market price methods estimate private value individuals derive from spectrum services/goods based on their purchase decisions in the market place.

Apply to goods/services in order to provide estimates of willingness to pay (**WTP**) based on market prices, as though, on relationship between demand and price.

Auction is the best way to capture Private User Value in making decision on potential allocation.

Economic (non-market) valuation methods

Technique	Description
Revealed Preference	Involves identification of complementary market good whose price captures the impact of non-market good.
Stated Preference	Relies on asking hypothetical questions via a survey (contingent valuation) or choice experiment (conjoint measurement), to see how people respond to a range of choices and to establish the extent of WTP for a particular benefit.
Deliberate Research	Aims to involve the public in decision-making. It enables a limited number of participants to find out more about a topic, consider relevant evidence, discuss this evidence and present their views on the topic.
Subjective Wellbeing	Uses subjective wellbeing data to attach monetary values to non-market goods. It relies on the availability of time series data that allows analyst to identify the impact of potential change in spectrum services on wellbeing.

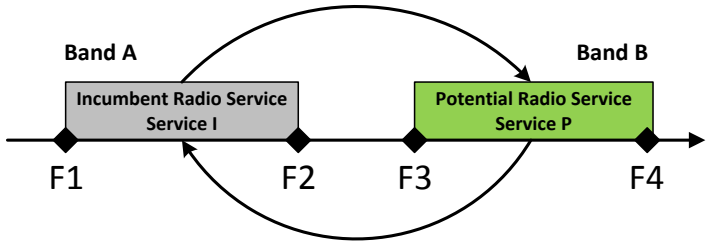
Source: Report to UK Department for Culture, Media and Sport "Incorporating Social Value into Spectrum Allocations Decisions", November 2015

If the costs and benefits of External Value are not taken into account, there is a risk to worsen results of re-allocation.

Simplified Case of Spectrum Re-allocation

Re-allocation represents an improvement if it results in an increase in the aggregate total value derived from spectrum services that would be affected by the change in allocation.

Proposed Reallocation Scenario



Incumbent (**Service I**) and Potential (**Service P**) services are proposed to exchange their spectrum bands.

A = costs of the services
B = Private User Value of the bands
C = External Value of the bands

Aggregate Total Value with Current Allocation

	Service I	Service P	Aggregate
	Band A	Band B	
A. Cost	200	300	500
B. User Private Value	300	500	800
C. External Value	400	100	500
Total Value to Society (-A+B+C)	500	300	800

Aggregate Total Value with Potential Allocation

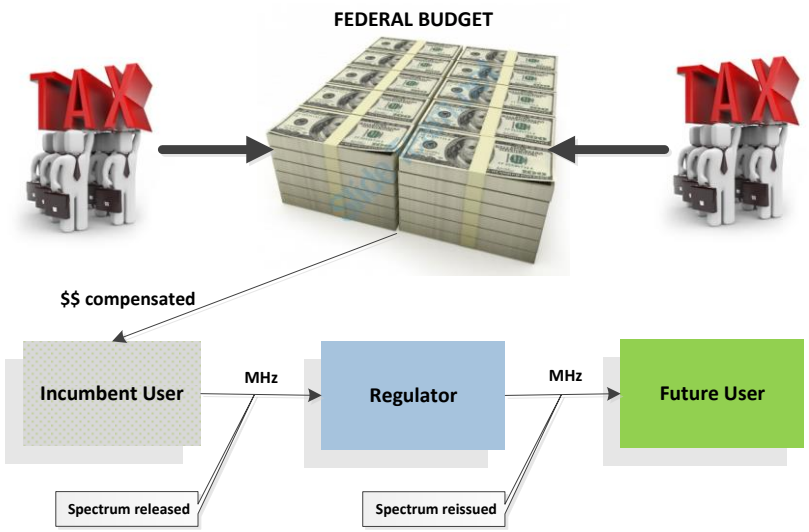
	Service P	Service I	Aggregate
	Band A	Band B	
A. Cost	200	300	500
B. User Private Value	700	300	1000
C. External Value	100	400	500
Value to society (-A+B+C)	600	400	1000

$$\textbf{Aggregate } (-A+B+C)_{current} < \textbf{Aggregate } (-A+B+C)_{potential}$$

Key criterion – potential aggregate Total Value exceeds current aggregate Total Value

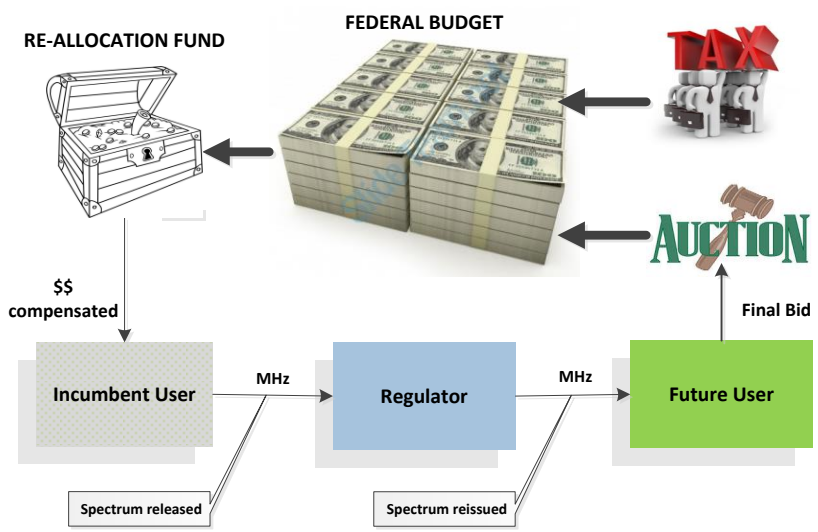
Landmarks in Re-allocation Financing

Re-allocation Through Federal Budget



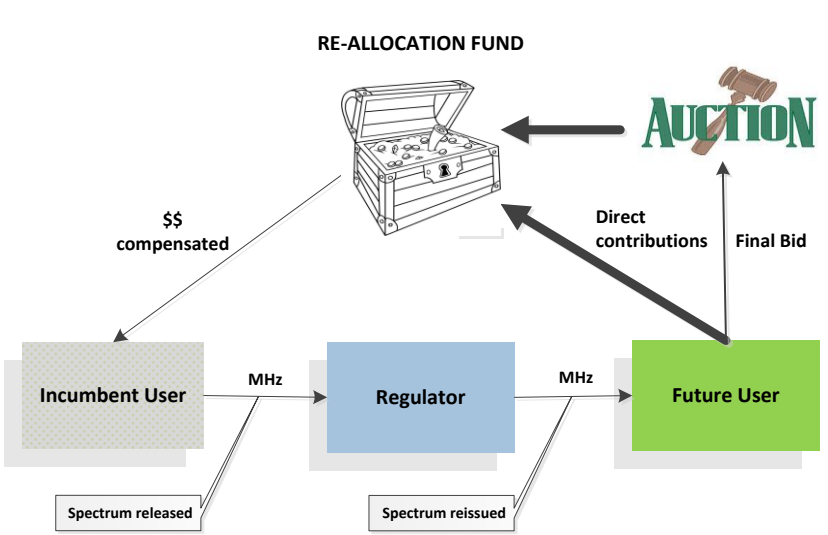
Pros: Typically the compensation funded by federal budget is connoted with a sort of governmental guarantees.
Cons: Non-spectrum users – ordinary taxpayers – are subsidizing spectrum related initiatives.

Re-allocation Fund Through Budget



Pros: In essence is similar to bank saving account. Can be financed through spectrum pricing at the primary stage of spectrum issuing (auctions).
Cons: Still might utilize subsidizing from non-spectrum users.

Directly Through Re-allocation Fund



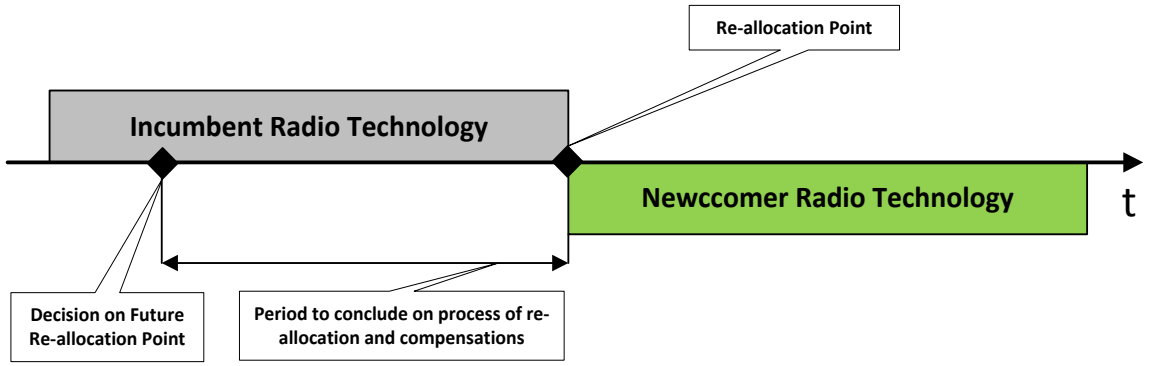
Pros: Re-allocation costs are covered directly by those interested in new allocations. Financial sources from auctions and spectrum fees.
Cons: Requires comprehensive mechanism of Fund's administration.

Re-allocation Classification and Timelines

Re-allocation Classification

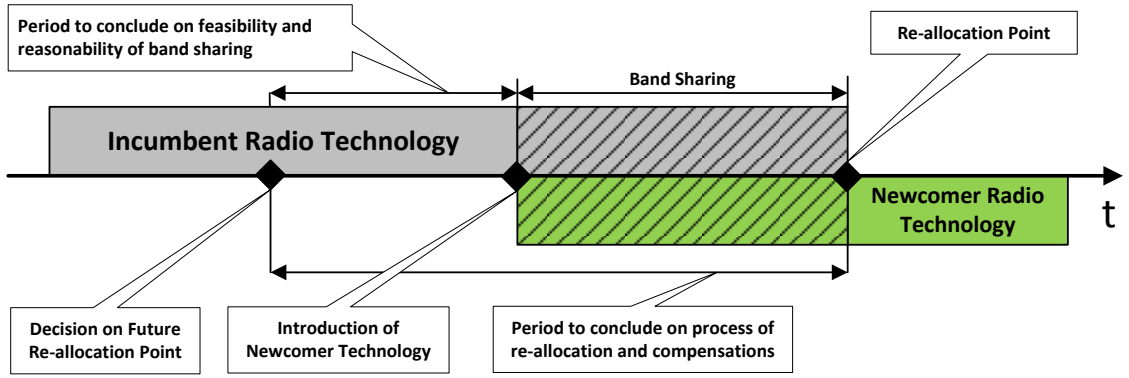
Between Private Users	Between Public and Private Users	Between Public Users
Market methods are preferred to decide on optimum and efficient distribution of allocations among users based on: ▪ Spectrum trading ▪ Spectrum pricing In a loose sense – Coase theorem and Pareto criterion. Incentive auction – innovative tool to facilitate spectrum turnover.	Economic methods should be applied to deal with compensations. Regulator estimates the cost of spectrum re-allocation. Re-allocation costs could be agreed as the reserve price for an auction.	Typically command-and-control methods. More arguable with introduction of market methods into the area of spectrum allocations of public sector.

Option 1. Re-allocation timeline, no sharing.



It is an incredible fortune for a regulator to intuit the correct Re-allocation Point of time. The raft of activities should be arranged in between the decision on and practical re-allocation.

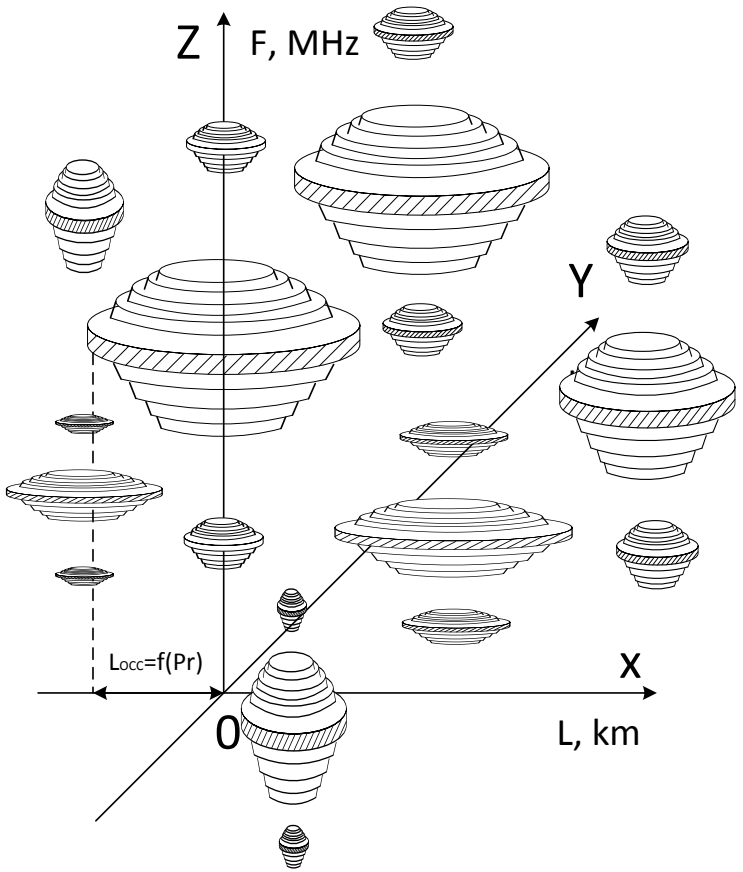
Option 2. Re-allocation timeline, spectrum sharing.

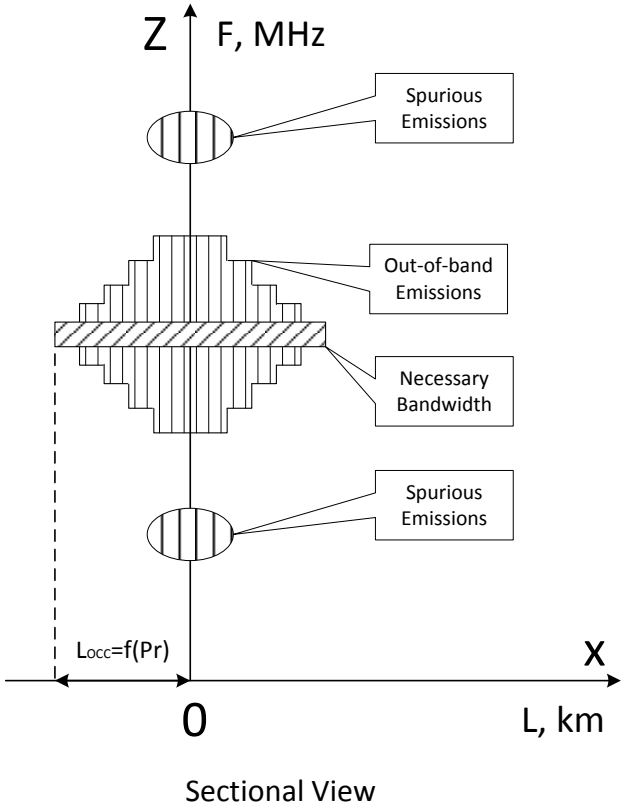


At large extent band sharing assists in fastest possible introduction of newcomer technologies. But it complicates the spectrum management and should not become an endless process.

Spectrum Utilization and Spectrum Sharing

Spectrum-Space Volume Occupied and Denied





Sectional View

Spectrum-space denied by incumbent to new entrant depends on spectral power density of emissions, antenna directivity, receiver sensitivity/selectivity, emission classes etc.

Spectrum Utilization

Spectrum Utilization Factor, U

$$U = B \times S \times T$$

where
B: frequency bandwidth
S: geometric space
T: time

Spectrum Utilization Efficiency, SUE for Spectrum Sharing

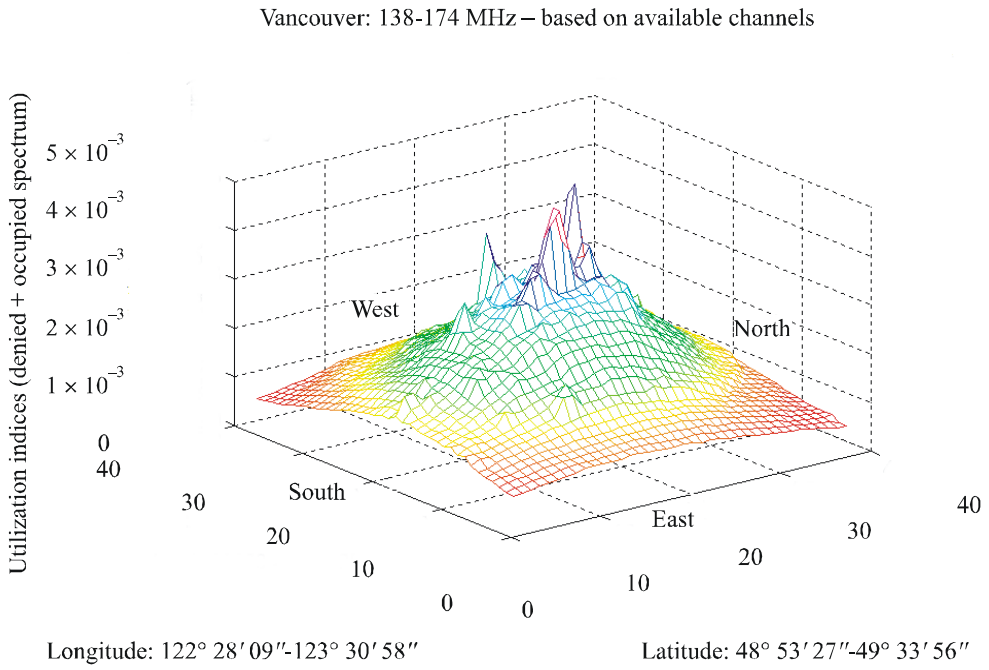
$$SUE = \frac{N}{B \times S \times T}$$

where
N: number of non-interfering radio stations within the band

Spectrum sharing is naturally restricted by the spectrum-space denied by different services. A band cannot be packed with the unlimited number of stations (saturation).

Spectrum Sharing versus Spectrum Efficiency

Spectrum-Space Volume Occupied and Denied



Source: Rec ITU-R SM.1046-2

3-D graphical representation for denied and occupied spectrum in the city of Vancouver for the band 138-174 MHz.

Spectrum Efficiency

In the engineering context Spectrum Utilization Efficiency of a shared band should maximize a number of radio stations operating on non-interfering basis in the given band.

Setting up of the problem in terms of **operational research**:

$$SUE = F[\alpha_1, \alpha_2, \dots;\ \beta_1, \beta_2, \dots;\ x_1, x_2, \dots],$$

where

$\alpha_1, \alpha_2 \dots$: factors in a-priory known (or operation conditions), unchangeable and non-influenced. E.g. incumbent service configuration, technical parameters of incumbent service, protection ratios, quality of services etc.

$\beta_1, \beta_2 \dots$: selectable factors (or elements of decision) are variable within the specified limits. E. g. entrant's infrastructure configuration (power levels, geographical separation, antenna directivity…), mitigation technics etc.

$x_1, x_2 \dots$: uncertainty factors (or uncertainty conditions) are unknown parameters that could not be predicted. E. g. evolution of demand for the services of incumbent and entrant, changes in electromagnetic environment etc.

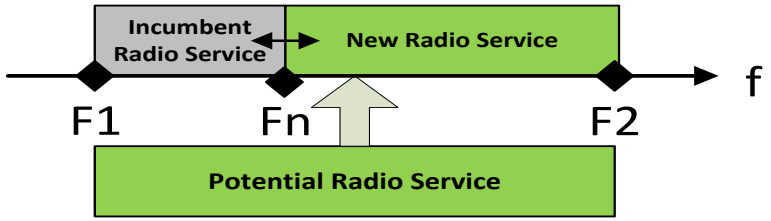
The task is to find SUE_{max} by choosing optimal β_i noting x_i.

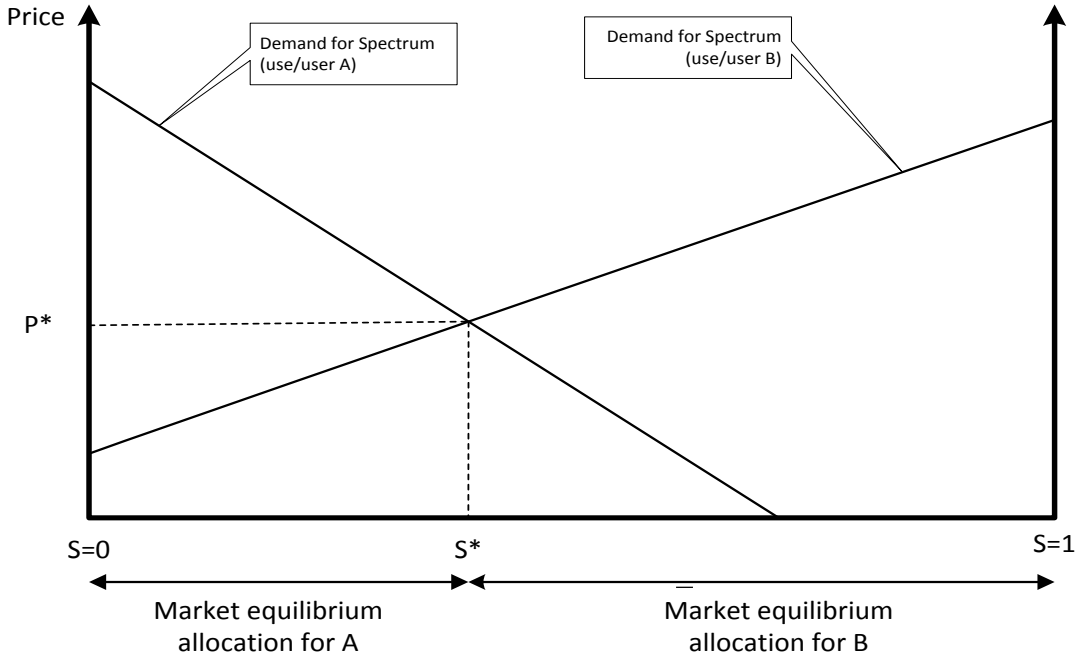
To note

$$SUE_{max} \neq Total\ Spectrum\ Value_{max}$$

Economic View on Limited Resource Allocation

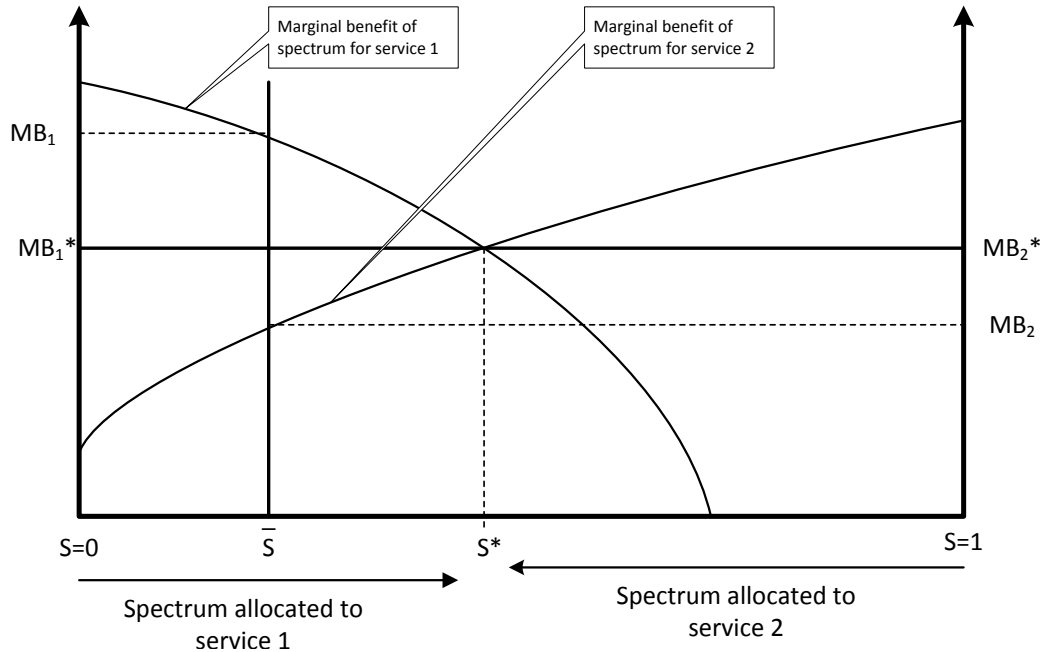
Subdivision with Spectrum Trading (Demand)





Source: Martin Cave, Spectrum Management, Cambridge University Press, 2015

Subdivision with Spectrum Trading (Marginal Benefit)



MB – marginal benefit of service

MB* – marginal benefit at point of efficiency

S - inefficient spectrum allocations

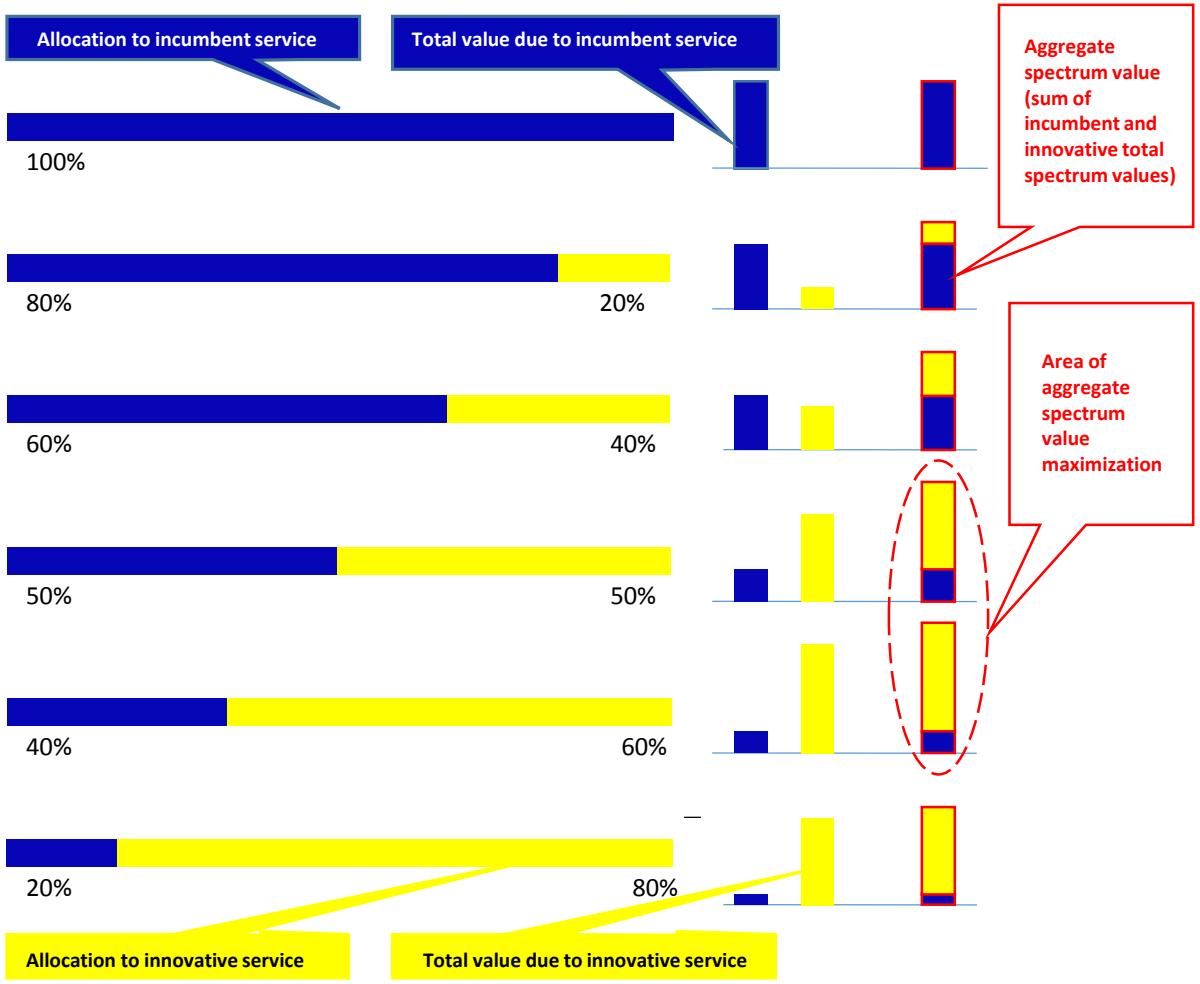
S* - efficient spectrum allocations

Source: Martin Cave, Spectrum Management, Cambridge University Press, 2015

The core challenge is to determine optimal ratio of spectrum resources allocated to incumbents and newcomers so as to maximize the total spectrum value. Market methods are highly eligible.

How to Obtain Efficient Re-allocation

How it works in practice…



How is it estimated…

Dynamic programming (dynamic optimization) is a method for solving a complex problem by breaking it down into a collection of simpler sub-problems, solving each of those sub-problems just once, and storing their solutions. Algorithm examines the previously solved sub-problems and combines their solutions to give the best solution for the given problem.

The task is to maximize target function ***Y(t)*** – economic benefit

$$\boldsymbol{Y(t) = max \sum_{k=0}^{n} y_k(x_k, t)}$$

where

n – number of radio services in the given spectrum band;

y_k – economic benefit from using k-radio service within the bandwidth x_k;

x_k – spectrum bandwidth allocated for k-radio service;

t – time, bandwidth allocated to services is variable in time.

The core challenge is to determine optimal ratio of spectrum resources allocated to incumbents and newcomers so as to maximize the aggregate social welfare. Market methods are highly eligible.

Non-Technocratic View on Spectrum Re-allocation. Conclusion.

With the experience gained in the last several years it is quite obvious that the technocratic approach with spectrum re-allocation is no longer all-encompassing.

- In conducting its strategic policy regulator should be emphasized with its duties to guarantee further interests of society including consumers, state needs, service providers, industry and to secure the optimal use of spectrum.

- The main incentive of administrations is to re-allocate spectrum in a way that maximizes the total value to society from its future use.

- The social-economic aspects of spectrum re-allocation are based on the fundamental concept of social value of spectrum resources usage. It is agreed that spectrum is used with the highest efficiency under the condition that the total amount of value for society (social value) created by its usage is maximized.

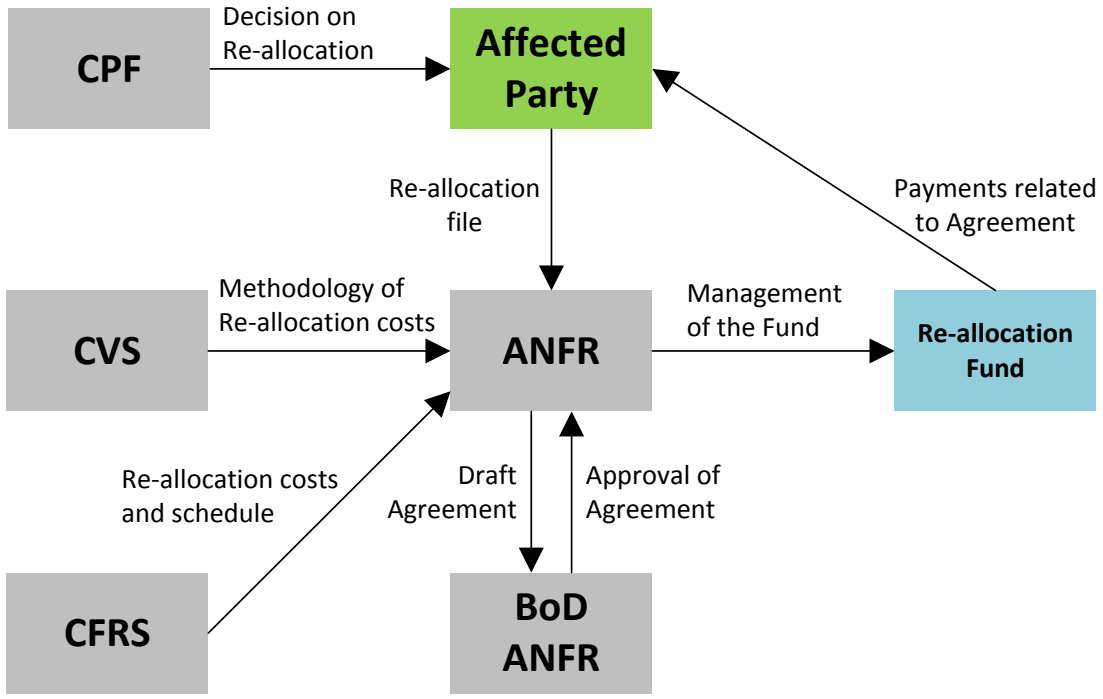
- The key objective is to guarantee the balance between retaining enough spectrum to provide the services of the incumbent users and releasing as much as possible for perspective users while maximizing total social value from the optimal reallocation of the whole band.

Spectrum re-allocation is the potentiality to obtain additional benefits to society arising from the optimal distribution of spectrum to innovative services taking due account of incumbent uses.

Annexes

Spectrum Re-allocation Fund in France

Re-allocation Fund Management



CPF - Commission pour la planification des fréquences
ANFR - Agence nationale des fréquences
CFRS - Commission du fonds de réaménagement du spectre

CVS - Commission de valorisation du spectre
BoD - Board of Directors

Practical Results

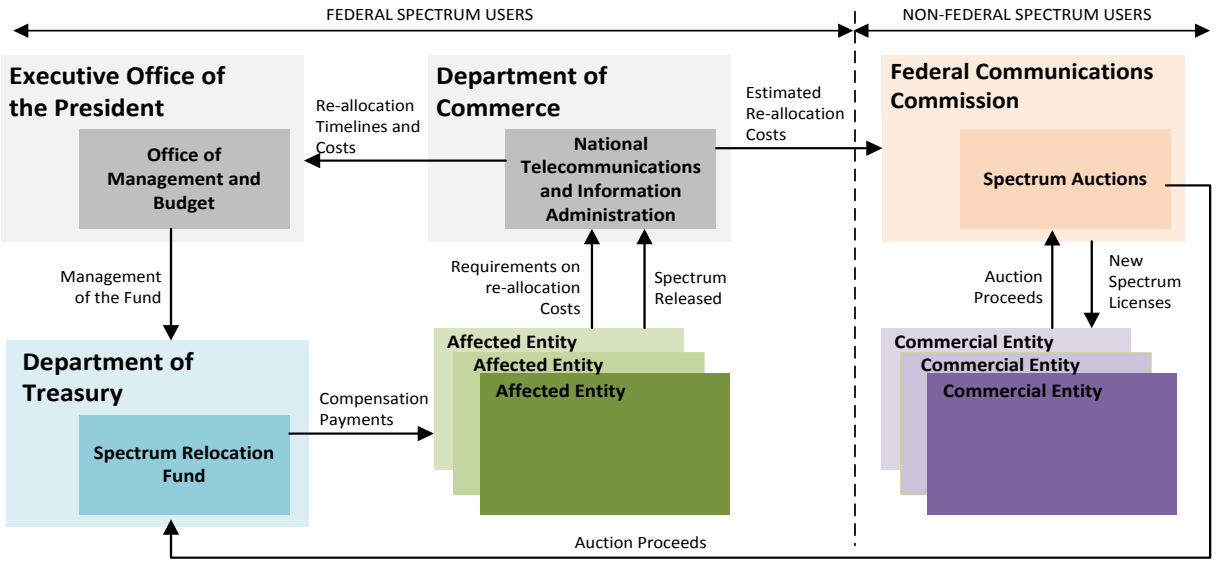
Systems	Spectrum Amount	Transferred from
GSM900	50 MHz	Defense
GSM1800	150 MHz	Defense
UMTS2100	140 MHz	Defense (partly)
WiFi2400	83 MHz	Defense
WiFi5 GHz	450 MHz	Defense, Meteo, Space
LTE2600	190 MHz	Defense
LTE800	40 MHz	Defense, Broadcasting

The Fund is established by Law and managed by ANFR. The money is used for required changes, bills are provided to ANFR. Every six months the newcomer refunds ANFR based on the amount of spectrum owned or on actual amount spend. If the newcomer is not known (auction has not taken place yet) ANFR takes expenditures from the ANFR accumulated funds.

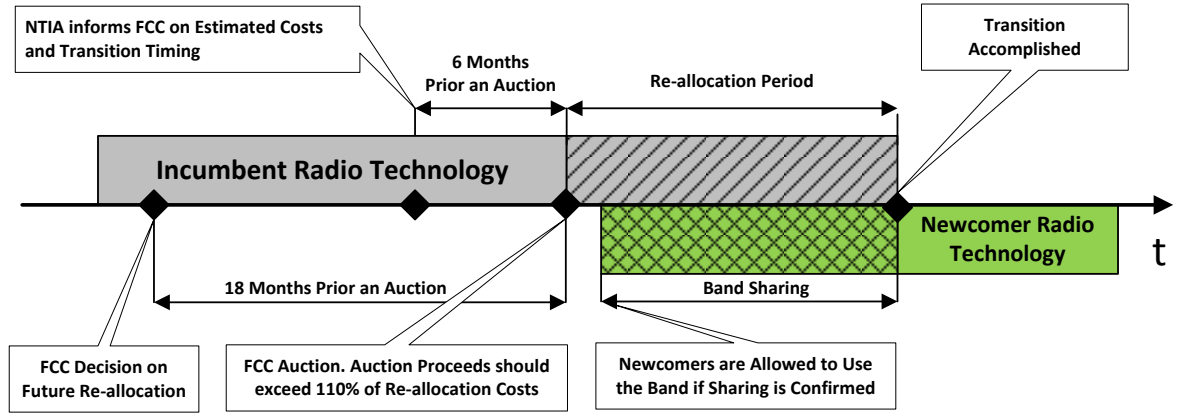
A “convention”/contract is produced between the three parties involved (existing user, new user and ANFR). This document sets out the modality for the move, financial implications and how ANFR will monitor and control this process.

Spectrum Re-allocation Fund in the USA

Re-allocation Fund Management



Practical Results



Primary Legislation on Re-allocation

Omnibus Budget Reconciliation Act, 1993	Identification bands of frequencies which meet certain criteria of re-allocation. Initial provisions on the process.
Commercial Spectrum Enhancement Act, 2004	Specifies provisions on the process of reallocation from governmental to commercial users. Establishes Spectrum Relocation Fund (SRF).
Middle Class Tax Relief and Job Creation Act, 2012	Extends reimbursement to spectrum sharing scheme. Requires agencies to submit transition plans for interagency management review of costs and timelines

1. FCC shall notify NTIA at least 18 months prior to the commencement of any auction of frequencies subject to re-allocation.
2. NTIA at least 6 months prior to an auction on behalf of the affected Federal entities and after review by the Office of Management and Budget, shall notify FCC of estimated relocation costs and timelines.
3. NTIA shall provide a Federal entity involved with information on alternative frequencies to which their radio operations could be relocated for purposes of calculating the estimated relocation costs and timelines.
4. FCC shall not conclude any auction of re-allocated frequencies if the total proceeds are less than **110 percent** of the total estimated relocation costs.
5. FCC may grant a new license for the use of frequencies under transition prior to the termination of Federal entity's authorization subject that the licensee cannot cause harmful interference to such Federal entity.

Auctions as the Instrument of Spectrum Re-allocation

AWS-1 1710 – 1755 MHz Auction with Compensation in the USA

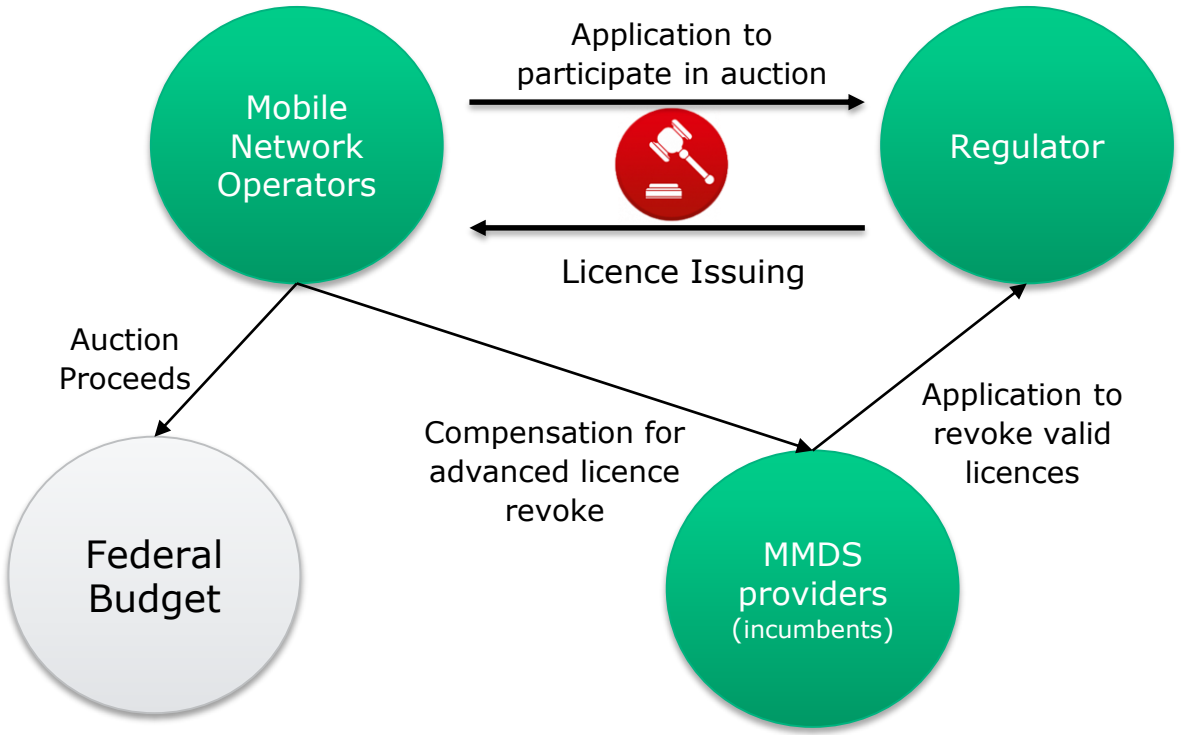
Table 1: Comparison of Estimated and Actual Relocation Costs for the 1710-1755 MHz Band (as of March 2013)

Department/agency	Estimated relocation costs[a]	Current actual relocation costs[b]
Agriculture	$21,578,486	$21,578,486
Defense	355,351,524	289,846,448
Energy	176,820,959	212,200,959
Homeland Security	89,994,832	282,239,840
Housing and Urban Development	21,115	21,115
Interior	25,411,949	31,936,326
Justice	262,821,000	556,424,000
Transportation	58,062,020	58,062,020
Treasury	5,301,000	5,301,000
National Aeronautics and Space Administration	740,000	740,000
Tennessee Valley Authority	10,687,857	15,751,057
United States Postal Service	1,761,760	8,333,760
Total	**1,008,552,502**	**1,482,435,011**

Source: NTIA, Relocation of Federal Radio Systems from the 1710-1755 MHz Spectrum Band: Sixth Annual Progress Report (Washington, D.C.: March 2013).

Actual costs to relocate communications systems for 12 federal agencies from the 1710-1755 MHz band have exceeded original estimates by about $474 million, or 47 percent, as of March 2013.
Although underestimated costs were well exceeded and covered with net auction proceeds 13.8 billion USD.

LTE TDD 2600 MHz Auction with Compensation in Russia

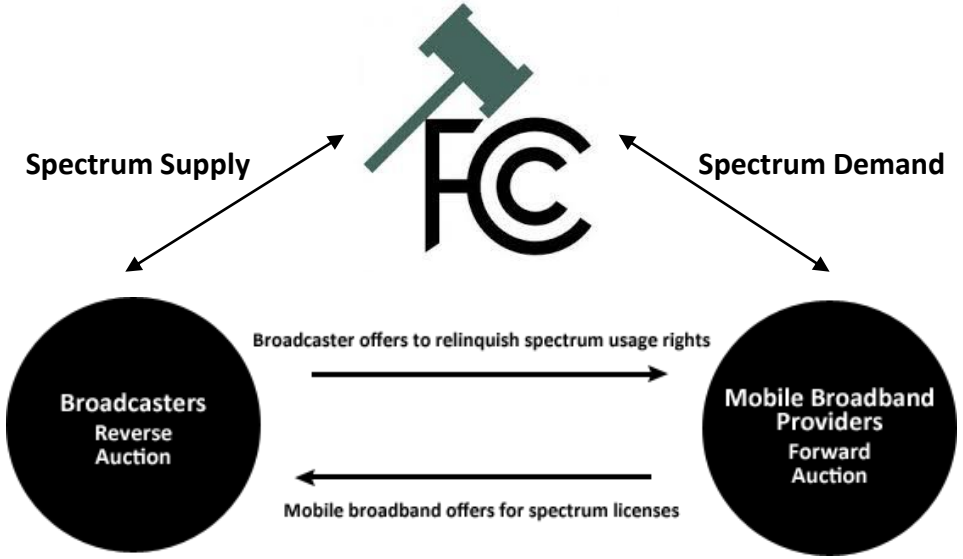


The concept included direct compensation payments from winners (mobile operators) to incumbent MMDS operators, while auction proceeds came to Federal Budget.
Compensation was calculated as the proportion of auction proceeds for the gained spectrum relinquished by incumbent MMDS provader.

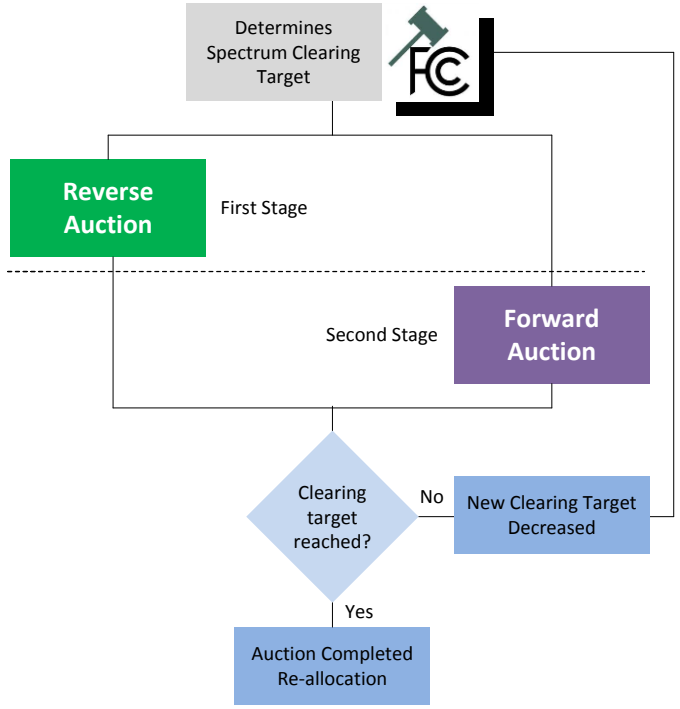
Incentive Auctions – Ingenious Market-Based Re-allocation Instrument

Concept of Incentive Auction

The FCC is serving as a matchmaker in 600 MHz incentive auction, going back and forth between broadcasters and bidders to settle on a price that strikes a balance between spectrum supply and demand



Auction Algorithm and Costs Distribution



Reverse auction

determines the price at which broadcasters will voluntarily relinquish their spectrum usage rights.

Forward auction

determines the price companies are willing to pay for flexible use wireless licenses in former TV bands.

Final Stage Cost Components

Auction proceeds are expended on three components:

1. Winning bidders' payments required for broadcasters
2. FCC's relevant administrative costs around $226 million
3. $1,75 billion – relocation costs for broadcasters

Incentive auction leaves market to decide on bandwidth to be released and prices to be paid for spectrum turnover

Thank You