Spectrum property rights: from theory to policy

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1 Introduction

"Spectrum is the electromagnetic lifeblood of the mobile economy and the mobile economy will become the driver of the digital economy in Europe. It is critical for Europe to have a spectrum strategy which will enable us to reap the maximum returns from this scarce and immensely valuable resource." [1].

For a long time spectrum management has been relatively static. Different radiocommunications services, as defined by the Radio Regulations [2] — an international treaty which governs the access to spectrum — have been segregated into different frequency bands. The national frequency allocations tables (NFAT) are usually based on the Radio Regulations and reflect such a band segregation, which made the spectrum management easier in the early days of radiocommunications when there was less demand.

The consumer demand in recent years for mobile broadband is unprecedented, and causes policymakers around the world to seriously reexamine spectrum management regimes. In the past decade, a multitude of proposals have been made to make the spectrum management more flexible, away from a *command-and-control* mechanism. Those proposals can be divided into two broad categories: 1) *market-based* approaches, based on economic theory and the strengthening of private property rights or 2) a spectrum *commons* approach, based on the engineering theory and the claim that technology will — in future — be able to handle interference situations automatically, and therefore property rights to spectrum would become irrelevant.

It has to be noted that the authors use the term "private property right" in its economic meaning (the economic "owner" is one who controls and micro-manages the resource), as opposed to the legal meaning (the legal owner of a resource). In France, the radio spectrum explicitly belongs to the public domain of the State (*domaine public de l'Etat*), thus any spectrum occupancy relating to non-governmental activities is considered to be

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a private occupancy of the public domain of the State, see [18]. In other countries, the radio spectrum does not explicitly belong to the State, but the State keeps the monopoly issuing spectrum usage rights.

This paper is divided into two parts. We will first review the relevant economic theory, starting with the seminal paper from Ronald Coase, The Federal Communications Commission [14], where the relevance of property rights in managing scarce resources was developed. In the second part of this paper we will dwell on recent spectrum management examples, where the economic analysis of "property rights" has been taken into account, both in managing interference situations (externalities), and efficient re-allocation of spectrum.

2 Economic analysis of property rights

From the point of view of the theory of property rights, it should first be noted that the resource that is coveted by the applicants is not necessarilly the wireless resource, such as frequency, but frequency bands dedicated to a given use for a given area during a given period. These resources for which operators compete are the licenses and not as such frequencies. The distinction is crucial, since it helps to explain the high variability of access prices to the resource, the spatial variability, variability in time.

The process that led to the transformation of frequency in licenses may be viewed in different ways: administrative authorization, allocation process through negotiations, competition in a free market...

We refer here mainly to Ronald Coase, Nobel Prize in Economics in 1991, according to whom it is efficient to allocate property rights to those who value them most.

The genesis of the Coase theory deserves to be remembered. The urging demand of radio channels by multiple TV stations in the immediate post-war at the expense of the major users of the time causes the first reflections on the economic value of spectrum (Herzel, 1951)[20].

Observing that private users of the spectrum are used to buy their inputs (machinery, land, ...) on the market in competition with other buyers, Herzel thinks that the radio resource, which is according to him only an intermediary consumption among others, has to be put in competition between potential users. He therefore proposes that the radio resource is open to competition between users as won by the highest bidder instead of being allocated for free or for a nominal fee. Implicitly, the state acts as an agent maximizing the income from natural resources it monopolizes, independently of any reference to the maximization of social welfare that it is supposed to realize. The issue in this reasoning appears when Ronald Coase focuses for the first time on this question in 1959, the year of the decision "Above 890". Based on specific examples, he first begins by showing the inability of the State to properly manage the spectrum resource on the basis of the regulation in place at that time (Coase, 1959) [14].

First, he emphasizes the arbitrary functions at the origins of inefficiencies in resource use. He quotes an FCC Commissioner who states: "I am finding it increasingly difficult to explain why a steel company in a large community, desperate for additional frequency space cannot use a frequency assigned, let us say, to the forest service in an area where there are no trees". Secondly, he shows the negative and perverse consequences of a free system. Local television, he writes, is to sell between at a price between 5 and 20 million US$. These amounts outweigh significantly the value of the transmitter, studio equipment, furniture, and the organization of these companies, which is nominally what is being purchased. The premium paid by buyers would correspond to the right of radio and television broadcast and thus to the access price to the spectrum. Thus, users of the spectrum sell downstream, a resource that the state granted them gracefully upstream. In more direct terms, the state is being looted and appears to be a poor defender of the interests of its citizens.

To remedy these shortcomings, Coase believes that the airwaves should be privately owned and freely transferable on a market. The analogy with the land is then introduced to justify this radical position. The land is available as a natural resource. It is a scarce resources in the sense that its surface is not extensible. It can be upgraded with alternative and competing uses (agriculture, industrial parks, office buildings, housing, etc..). It is saturable as a portion of land can be used for multiple uses or users.

According to Coase, the spectrum has identical properties to the land. But unlike it, the spectrum is not appropriated by private entities and is not valued on a market. To explain this incongruity, Coase pointed out that a market can only exist on the basis of recognition of property rights guaranteed by the law that imposes sanctions where these rights are not respected. For the spectrum, these rights did not exist when the private radio stations developed in the United States during the period between the wars. This lead to a wild conquest of spectrum including bands used previously by the Department of Defense (DoD). Therefore, interference problems quickly arose that made inaudible almost all radio communications and jammed the DoD. In the absence of any property rights, private users were unable to resolve conflicts caused by interference using conventional contractual or legal methods.

How then arbitrate conflicts over resource use between resource users who cannot claim any entitlement on this resource?

The disastrous experience of competition in gaining spectrum access, quick resource depletion, and management of conflicts without ownership triggered the 1927 law that gave the U.S. state ownership and authority over the entire radio spectrum, instead of the establishment and recognition of property rights to resource users. For Coase, this was a historical error that should be corrected. The creation of property rights in the spectrum transferred to spectrum users is desirable. According to him, on the basis of the full ownership rights, a market will emerge from demands and supplies of the property rights as well as occupancy contracts (lease, rent,...) of the resource. This organization will promote a better use of resources than does the centralized management system whose failures are quite evident today. Free contracting refers to the ability to tie and untie quickly and freely arrangements between multiple stakeholders with diverse needs.

For the theory of property rights the issue is there. We need to transform a public resource into private property. However, aware of the significant externalities associated with the use of the spectrum (he mentions Pigou on this point), Coase thinks that the state cannot disengage itself completely from the functioning of this market. Regulatory authorities shall have the duty to limit the power of radio or television, as a special market where individual initiatives can affect millions of individuals (remember that Coase was a freelance journalist for BBC1). It also seems imperative to reserve some bands to uses where the public interest seems obvious (defense, police, fire, ...). If necessary, the government intervention will alter property rights of users, this will affect the market price of the relevant frequencies and cause desirable reallocations. Thus Coase evokes a frequency zoning that could be set up, similar to a land use plan, under certain circumstances and for certain bands.

Analyzing frequency management of government agencies provided by the RAIC Coase expands its analysis and emphasizes the integration of users in the state of market mechanisms (e.g. military) (Coase, 1962). This confrontation of non-profit organizations to competition would facilitate, according to him, the efficient reallocation of spectrum, limit the risk of excessive allocations to some users, and thus limit the waste inherent in the administrative management of the radio spectrum. These papers appeared to be highly innovative and constitute today some basic references, often cited but not necessarily read and perfectly understood. Some economists contest the Coase logic (Melody, 1980 Withers, 1989), but many researchers will develop Coase intuitions (De Vany, 1998[17]; Hazlett, 2003).

Two points are of particular importance. First, it seems important to identify the reasons why the market could be more efficient than a centralized spectrum management organization and, secondly, the question of the transition from one system to the other in the event that this solution would be retained.

About the first question, the debate clearly refers to transaction costs inherent in the functioning of markets: searching information, drafting contracts, interference control procedures, technical frequency planning, etc.. are all costly. Aren't they ultimately much higher in a decentralized system, because they are systematically duplicated, rather than in a centralized system where they are not? More importantly, does the potential spectrum fragmentation induced by uncoordinated individual initiatives, which may generate technical and commercial irreversibilities, lead to a better allocation and use of spectrum resources in a centralized system? Is land management left only to market more efficient than if it is the subject of centralized management? The answer is not as obvious as it seems at a first glance. We lack of adequate empirical comparisons and in the absence of fully convincing theoretical models, the preference for the market sometimes stems from intuition.

The issue of transition between the two systems has undoubtedly resulted in more analysis. However, the authors are less interested in this perspective to the entitlement itself as relations between owners and users through concession contracts granted for the use of spectrum. Three types of proposals dominate the literature on these concessions

- they should be allocated in an auction;
- they should be freely transferable throughout their life;
- the price of the auction shall be assessed to the opportunity cost, that is to say the cost of substitution between or among media transmissions uses where possible, or by other means when the band does not support alternative use and can not be substituted by any other means of transmission of signals.

Some remarks are necessary on these points. The auction of the frequencies involved the simultaneous realization of three possible objectives: create property rights, optimal allocation of frequencies and maximization of the State income by selecting objective and transparent mechanism. Theoretical research on auction mechanisms has made remarkable progress in recent decades. However, the results obtained so far do not guarantee for sure that auction in the frequency domain process will lead to desired outcomes (see e.g. the recent auction in Britain in 2013, far from having expected results). In fact, the auction mechanism does not affect the single market rates. Indeed, the price and quantity of acquired spectrum interact, obviously, with the operation of downstream markets using the spectrum). The auction mechanisms on the spectrum must, strictly speaking, consider these interactions and therefore be part of an analysis in terms of overall balance. However, auction theory produces results essentially in the analyzes in terms of partial equilibrium, it is still struggling to integrate the mentioned interactions between different markets. Therefore, among the three objectives sought, only the first is certainly achieved, namely the creation of property rights. However, there is no guarantee that the other objectives will be achieved: this is a real problem. This explains why other mechanisms than auctions are still in place in some countries.

The license period is, in the models, exogenous to the auction. Or, in case of competition between alternative uses, the duration of the license is no longer neutral on the outcome of the auction. Thus, for a license period of five years, uses with the return time of the shortest and less than 5 years investments are favored over others. They give a net flow of income to enable them to win the auction. The same tender passed a 10-year license may cause a reversal of the profitability of projects. Uses considered in the first case would then be in a favorable position in the second case. This is a classic problem of investment choices. The result of the auction, and therefore the distribution of frequencies depend on the duration of the license, that is to say, the preference for the present administration of the selling, highly subjective criteria. A subjective criterion can be substituted, the preference for the purpose of administration. Based on this preference, the seller will determine the duration of licenses. Solution almost status quo in relation to the current situation where the government decides on the distribution of uses across the spectrum. The license period is defined in terms of usage, competition auctions (competition for the market) committed only use the same suppliers. Of course, nobody imagines auction for a definitive assignment of spectrum by the state (infinite duration of the license). But this is why it should be held if one follows the logic ... Coase licenses therefore have a limited life and raises the question of renewal so the lack of certainty of an occupant can continue indefinitely operation except to give perpetual occupation of rights ... - How to manage the transition between the two systems? What is the process of creation of property rights? What is the value of the radio spectrum? How to evaluate on a basis acceptable to all parties involved? Both types of questions will lead to specific investigations in the theory of property rights.

On the first point, Coase, Minasian and Meckling (1963) [16] model the first articles of Coase and try to introduce transaction costs. Indeed, starting from a completely ad hoc assumption that transaction costs are lower in the case of the market, and they actually show no surprise that this form of organization is more efficient than centralized management. Continuing in this way, Minasian (1969) published a landmark study to demonstrate the mechanisms of competition in force for twenty years. Six years later, he produced an extremely thorough typology of transaction costs associated with the management of the radio spectrum (Minasian, 1975) [21]. He studied many potential forms of reallocation of spectrum taking into account the constraints of interference. The goal is to raise the doubts of engineers and authorities about the feasibility of determining the rights of private property on the spectrum and the efficient functioning of a market on the basis of the ownership split between spectrum users. The central idea consists to consider that, as in the land case, management of property rights in the spectrum simply means to build "electronic barriers" (Mueller, 1988) which will be scalable based innovations and reallocations. If the mechanisms presented prefigure the modes of organization and administration of a spectrum market no systematic evaluation of the costs of the market has been performed routinely (costs of electronic barriers,...).

It is true that instead of comparing the costs of alternative management systems, studies within the framework of the theory of property rights are especially attached to precisely quantify the costs and inefficiencies of centralized management. These inefficiencies are considered as savings to be made through the market (Jonscher, 1987). The disadvantages associated with the operation of the market are mentioned but rarely evaluated, it also understood by advocates of centralized management. It is also true that the lack of certainty as to the renewal of licenses, the radio resource is usually treated by buyers license as an exhaustible resource. Indeed they maximize their objectives in terms of a resource they have a limited period. Turn through a legal-economic mechanism, an inexhaustible resource in physical terms in an exhaustible resource in legal and economic terms, probably not only leads to an optimization of the use and allocation of frequencies. The fusion status of the owner and operator of the resource represents a way to permanently remove this obstacle. But how to create private property rights in conditions of economic optimality irrefutable?

Failing to provide a definitive answer to this question, our goal is to demonstrate through concrete examples how the market could improve spectrum management (in Pareto sense). From this field experience, we want to show that the choice of a spectrum management approach based on the recognition of property rights, as opposed to a centralized administrative management, can be made wittingly on solid management criteria.

3 The role of property rights in spectrum management decisions

At the time Coase wrote, many economists saw market failures as commonplace, and government action as the correct response. Specifically, externalities — such as sparks from a passing train setting fire to a farmer's crops, or emissions from a radio transmitter interfering with another's signal — were seen as evidence that the market was not able to allocate resources efficiently. Government regulation, or even direct ownership and control, was seen as a sensible solution.

In "The Federal Communications Commission" [14], Coase directly challenged this view. So long as property rights were clearly defined and transactions costs were low, externalities could and would be addressed by the market itself, through private negotiations between the affected parties. Moreover, it did not matter to whom the property rights were initially assigned, as the parties would trade among themselves to achieve the most efficient economic outcome.

This work — expanded upon a year later in "The Problem of Social Cost" [15] — ultimately won him the 1991 Nobel Prize in Economics, "for his discovery and clarification of the significance of transaction costs and property rights for the institutional structure and functioning of the economy."

In the following two sections we will develop recent examples where property rights have played a role improving spectrum management decisions. The first section 3.1 will show two examples where property rights have played a role in interference management (externalities); the second section 3.2 shows two examples where property rights play an central role in achieving optimal allocation decisions through Coasian bargaining and lowering transaction costs.

As developed in *Exactitude in Defining Rights: Radio Spectrum and the 'Harmful Interference' Conundrum*, by Thomas Hazlett and Sarah Oh, the definition of property rights in spectrum does not need to be perfect. Additional clarity in spectrum rights — as with property rights generally — is preferred to less clarity, all else equal. But perfect clarity (or exhaustiveness) is not achievable, and additional clarity is costly. As De Vany et al. wrote in their 1969 study, "Complete certainty in this regard is not necessary for the functioning of a market." Enormously high social value is delivered with easily defined spectrum borders, when compared to the cost — and delays — of specifying more complete use rights. When regulators succeed in delegating flexible use rights to a responsible economic agent, specifically an organization constrained by profit maximization, the problems associated with "ill-defined rights" dissipate. Such basic rights are available in the templates used to assign spectrum use rights to mobile operators around the world. When these are distributed in a manner that avoids excessive fragmentation, the ills associated with disputes over "harmful interference" are almost entirely avoided.

3.1 Property rights and externalities

Until Coase, externalities were seen as bad acts, the willful imposition of harm by a wrongdoer on an innocent victim. Given this characterization, the appropriate policy objective was to stop the wrongdoer and make the victim whole. But Coase explained that the relationship between the party *imposing* the externality and the one *affected by* it was in fact reciprocal (Coase 1960) [15]:

> *The traditional approach has tended to obscure the nature of the choice that has to be made. The question is commonly thought of as one in which A inflicts harm on B and what has to be decided is: how should we restrain A? But this is wrong. We are dealing with a problem of a reciprocal nature. To avoid*

the harm to B would inflict harm on A. The real question that has to be decided is: should A be allowed to harm B or should B be allowed to harm A? The problem is to avoid the more serious harm.

For example, a rule prohibiting a locomotive from emitting sparks into the farmer's fields imposed costs on the railroad that are no different, in kind, from the costs that would be borne by the farmer under a rule requiring crops to be planted further back from the tracks. The Coasian objective, then, is to determine which rule imposes the least costs on society overall — whether it is more efficient, that is, to retrofit the locomotive to stop producing sparks, to plant the crops further back from the tracks, or, perhaps, to simply let the crops burn.

Spectrum management is often based on an "anteriority rule", which means that users that are registered in a national spectrum database enjoy protection with regard to all subsequent users in the band, unless otherwise specified. Recently, this anteriority rule has been extended to cope with interference situations between users in adjacent bands, and not only users in the same band. Such an anteriority rule provides legal certainty, but it can hamper innovation and technological progress in some cases. All the burden of protecting existing users is borne by the newcomers.

In the following two subsections, 3.1.1 and 3.1.2, we will analyze how the introduction of economic property rights and a pricing mechanism has influenced the spectrum management decisions in different interference situations.

3.1.1 Interference from 4G base stations into air traffic control radars

In 2011 France held an auction process on the 2.6 GHz for mobile broadband. The band just above the new band for mobile broadband at 2.6 GHz is used for air traffic control radars (ATC) at civil and military airports. The problem comes from the fact that many radars are quite old. They are supposed to operate in the 2.7 - 2.9 GHz band, but in fact many of them can "hear" signals down as low as 2.4 GHz. That means that LTE signals in the 2.5 - 2.69 GHz band could interfere with ATC radars, which is clearly not a great situation.

The answer is to put filters onto the airport radars to make them operate only in the 2.7 - 2.9 GHz band. However, the upgrade of the existing radars comes with some costs, which was estimated between 1 M€ (including a filter, engineering cost, and certification of the new system) and 5 M€ (approximately the cost of a new radar). There were less than 10 ATC radars in France, close to dense urban areas. The total "clean-up" cost would have been a maximum of 50 M€, a fraction of the reserve price for the 2.6 GHz band which was set to 700 M€ by the French government.

Upgrading a radar solves most of the problem, but not all of it. After the upgrade of a radar, the mobile operators need to take some technical measures in the close vicinity of an airport radar. Until the upgrade however, the area where such technical measures are required are within a radius of several tens of kilometers around the airport radars. That means that major parts of Paris, Toulouse, Nice and Strasbourg, not to mention the affected airports themselves would not have been able to have 2.6 GHz mobile broadband until the operators were given the all clear. The 2.6 GHz band is part of the "higher" bands, which are used for capacity extension in dense urban areas, as opposed to the "lower" bands (e.g. 800 MHz) which are used for both coverage and capacity. Restricting the use of the 2.6 GHz band around major cities would have significantly reduced the usefulness and value of this band. Such a potential decrease in value of a 2.6 GHz band with major restrictions around airports was much higher than the cost of upgrading the radars. The interference problem is a reciprocal one.

The question before the auction was: who is going to pay for the upgrade of these radars? The lucky winners of the 2.6 GHz auction through post-auction negotiations with the civil aviation authority (each operator individually), or the French authorities taking a of the auction revenues to upgrade the radars and sell "clean" spectrum to the operators.

According to the legal framework in place, any interference situation between users in adjacent bands would be dealt with using the anteriority rule.The ATC radars were of course registered in the national spectrum database long before the 2.6 GHz auction process begun.

The legal situation was clear: the mobile operator would have to pay for any interference he caused to the ATC radars, as there was no obligation nor commitment from the radar operators to upgrade their system. Furthermore the civil aviation authority did not have the necessary budget resources to upgrade its radars in a short time-frame.

This existing legal situation made the valuations for the 2.6 GHz spectrum very difficult prior to the auction. The auction process was indeed a two step process: in a first step, operators bid on spectrum quantities from $2 \cdot 10$ MHz up to $2 \cdot 30$ MHz (spectrum cap), in a second step the highest bidder (per MHz) could choose its relative position in the 2.6 GHz band, closer or farther away from the radar band, followed by the second highest bidder (per MHz) and so on. It was also likely that the first operator to roll out mobile broadband at 2.6 GHz band in a city would have to pay for "clean-up" costs and the subsequent roll-outs would benefit from this without bearing the costs, which is clearly a free-rider problem.

The French mobile operators raised this issue with the national authorities — the national regulator, Autorité de Régulation des Communications Electroniques et des Postes (ARCEP), the national spectrum agency, Agence Nationale des Fréquences (ANFR) and the ministry of economy and finance

— in a letter in April 2011. Basically two solutions were possible before the auction:

- either the auction could take place under the current regulatory regime "anteriority rule", letting the operators negotiate with the relevant government agencies after the auction to upgrade their system (and pay for the upgrade). Obviously the operators would reduce their bids by the estimated amount of money they had to pay for the upgrade of the radars.
- or, alternatively, the administration could internalize the interference problem and sell "clean spectrum" without major interference problems.

The final auction rules for the 2.6 GHz band were published on May 31st, 2011, in the decision n°11-0598 from ARCEP [3]. A companion decision n°11-0597 from ARCEP [4] presented the detailed technical conditions for the use of the 2.6 GHz by mobile broadband. This second decision explicitly maintained the "anteriority" rule. The French administration agreed however to internalize the interference problem and requested the civil aviation authority, the meteorological authority and the defense ministry to "take all possible measures to upgrade their radars *before* the roll-out of 4G LTE services in the area". This decision was published in May 2011 on the ANFR website, which has not legal status[1], and the final schedule for upgrading the ATC radars was set in July 2012, almost a year after the auction, taking into account the roll-out plans of the different operators.

The authors assume that this decision to internalize the clean-up costs was taken to maximize the final revenues of the auction including the cost of upgrading the radars. This solution minimized the transaction costs as it was more efficient to handle the coordination directly by the administration (a single stakeholder) rather than to let multiple the operators negotiate individually with the different authorities. This solution also minimized the risk for the operators taking part in the auction process.

The introduction of a pricing mechanism and *de facto* property rights in the 2.6 GHz band (auction process), made it possible to find an economically efficient solution for the resolution of this interference problem.

The total auction revenues for the 2.6 GHz band were 936 M€.

3.1.2 Interference 4G base stations into TV receivers

Coase also recognized, however, that such bargaining was not always possible. There are times when the costs of negotiating among multiple parties would make market solutions infeasible, [14].

[1]http://www.anfr.fr/fr/planification-international/etudes/compatibilite/bande-2700-mhz.html

> *When the transfer of rights has to come about as a result of market transactions carried out between large numbers of people or organizations acting jointly, the process of negotiation may be so difficult and time-consuming as to make such transfers a practical impossibility ... In these circumstances it may be preferable to impose special regulations (whether embodied in a statute or brought about as a result of the rulings of an administrative agency).*

An example of such an interference situation, including a high number of affected parties, is the interference between mobile broadband base stations in the 800 MHz band, 790-862 MHz, and TV reception in the band just below, 470-790 MHz. Prior to 2005, the full 470 - 862 MHz — including today's mobile band — was used by analog TV broadcasting and some military operations at the top of the band. The analog TV was progressively replaced by digital TV between 2005 and 2011 when the last analog TV transmitter was switched off. The digital TV was much more spectrum efficient, and this technological migration allowed the introduction of new TV channels, as well as making part of the band (790-862 MHz) available for new mobile broadband services: the first "digital dividend" was born.

After the analog switch-off in 2011 there were no more TV transmitters, neither analog nor digital, in the band 790-862 MHz. However, both the TV receivers that were sold before — and in fact even after — 2011 are capable of receiving in the full 470-862 MHz band, including the band currently used for mobile broadband. Some of these receivers could turn "blind" when the 4G signal is much stronger than the TV signal they're supposed to receive in the band below. This situation occurs in the vicinity of a 4G base station, especially when such a base station is located in between the TV transmitter and the receiving household. In areas with poor TV reception, a pre-amplifier is required to receive the TV signals correctly; such pre-amplifiers actually make the the interference situation with 4G base stations worse.

The solution, again, is to insert a filter at the TV receiver of the individual households, including a sufficient attenuation of the band 790 - 862 MHz. Such a remediation can only take place *a posteriori*, when an interference case has been reported.

The main difference with the previous example at 2.6 GHz is that there are many more TV households than radars that could potentially be interfered, and there was no single organization such as the civil aviation authority to negotiate with.

The auction rules for the 800 MHz band were published on 31st May, 2011, in decision n°11-0600 from ARCEP [5], and a companion decision n°11-0599 [6] detailed the technical conditions for the use of the 800 MHz band for mobile broadband. This decision is based on the "anteriority" rule again and stipulates that the users of the band 790 - 862 MHz "must take all necessary steps to reestablish the TV reception, either by switching off the emissions that cause the interference or any other appropriate means".

It is of course not possible for the mobile operators to negotiate individually with all the interfered TV households. To deal with this problem, the mobile operators and the French spectrum agency ANFR agreed to set up a call center — centrally managed by the agency — which collects and diagnoses the interference cases, based on the complaints from the TV viewers. The analysis that is performed by ANFR takes into account the technical characteristics that were provided by the mobile operators in their administrative declarations, and — most importantly — the exact date when the base station was switched on.

This setup is still in an experimental phase. It is easy to allocate a complaint to an operator when he is the only one to roll out in an area. When several operators are rolling out in the same area at the same time, the allocation of complaints to the operators responsible for the interference turns out to be much more complicated. The TV viewers are to some degree resilient to TV interference (perhaps a habit they took during the analog-digital switch-over), and do not always report interference cases immediately. Bad TV reception can also be caused by atmospheric conditions, and some bad reception problems simply disappear; others don't. At this stage, there are still a number of false alarms where the interference does not come from the mobile operator which was identified as causing it.

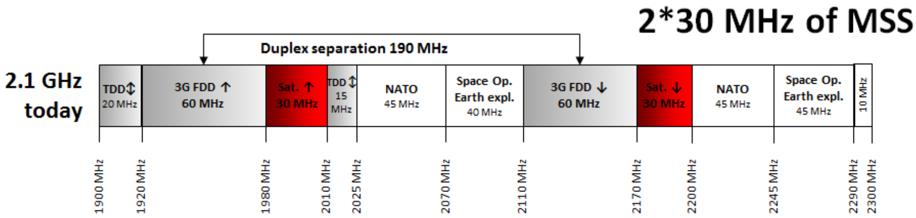
This example shows that even with a high number of potentially interfered victims, the efficient solution is not always Pigou-style taxes or *a priori* regulation for "polluters". It can also be *a posteriori* remediation interference problems where they occur. The *coordination problem* was efficiently solved by the French spectrum agency (ANFR) and the operators setting up a centralized call center, which gathers and diagnoses the interference problems, and allocates them to the operator responsible for it. In addition, operators establish contracts with local companies who coordinate the actions of the antenna technicians in the areas of 4G roll-outs. The operators each pay their share of the cost of the call center.

The auction at 800 MHz in December 2011 yielded 2.639 billion euros in revenues.

3.2 Property rights and Coasian bargaining

This section provides two examples where property rights in spectrum enable Coasian bargaining and efficient re-allocation of spectrum.

Figure 1: Mobile spectrum around 2.1 GHz, terrestrial and satellite



3.2.1 Liberalization of the mobile satellite spectrum at 2.1 GHz

The bands around 2.1 GHz provide an interesting opportunity for Coasian bargaining between different stakeholders. These bands were identified by the International Telecommunications Union (ITU) for both terrestrial and satellite third generation mobile systems, back in the 1990's. This decision was taken at the 1992 ITU World Administrative Radio Conference (WARC-92) and the band plans were finalized in 1999, as shown in figure 1.

Out of the 215 MHz available in Europe, $2 \cdot 60$ MHz (120 MHz) were made available for terrestrial mobile systems, and $2 \cdot 30$ MHz (60 MHz) were set aside for satellite systems.The terrestrial systems quickly developed in the early 2000's and are now among the most used spectrum bands in a large number of countries where they are part of the core 3G bands; North and Latin America use different arrangements. The satellite systems have yet to prove to be a commercial success and the spectrum remains largely unused.

The portion that could be used by mobile satellite services (MSS) was arbitrarily set to one third of the available paired spectrum. At the time these decisions were taken the satellite component was considered an important part of a future mobile system, because of its potential for wide coverage once the first satellite was in orbit.

From a technical point of view, it would be relatively easy to extend the existing terrestrial band plan into the satellite bands, as they have the same duplex spacing of 190 MHz and the same duplex direction (uplink/downlink). Furthermore the satellite bands are perfectly harmonized on a wide scale (positive externalities), and there are no major interference issues (no negative externalities).

On the satellite side, a number of European decisions have been taken to make the band available on a pan-European level, and harmonize the technical conditions for mobile satellite services in each Member state, starting with the "Harmonisation Decision" [7]. A further co-desision of the Parliament and the Council provided a selection and authorization process for pan-European mobile satellite systems [8], and on 13 May 2009 the Commission selected two operators Inmarsat Ventures Limited and Solaris Mobile

Limited, as the undertakings to provide MSS on a pan-European basis in the 2 GHz band in the EU [9]. Each of them have $2 \cdot 15$ MHz of spectrum.

The 2008 decision [8] also allows the satellite operators to roll-out a "complementary ground component" (CGC). According to the decision, CGC "shall mean ground based stations used at fixed locations, in order to improve the availability of the mobile satellite service in geographical areas within the footprint of the system's satellite(s), where communications with one or more space stations cannot be ensured with the required quality". This was to make sure that mobile satellite systems can also be used in dense urban areas, where the direct visibility to the satellite is not guaranteed. However, it is not allowed under the current regulatory framework to use these bands for independent terrestrial networks: "the CGC shall constitute an integral part of a mobile satellite system and shall be controlled by the satellite resource and network management mechanism". It is therefore not allowed to roll-out an independent terrestrial network in the band.

In the United States, a similar project was developed by LightSquared to use the MSS spectrum in the L-Band around 1.5 GHz for terrestrial broadband. Initially the LightSquared spectrum was also restricted to hybrid networks, a satellite component together with an "ancillary terrestrial component" (ATC), similar to the CGC in Europe. In January 2011, the Federal Communications Commission has removed these restrictions ("the integrated service rule") on the mobile satellite spectrum in order to allow for future use by terrestrial wireless broadband systems, [10]. This waiver was granted under certain conditions: LightSquared agreed to continue the development of hybrid satellite-terrestrial handsets, as well as coverage obligations of 260 million in population by the end of 2015. The LightSquared project unfortunately turned out to be unsuccessful because of rights fragmentation in the adjacent bands, and lack of organizations to negotiate with (Hazlett, Skorup 2013)[19].

In Europe, the Radio Spectrum Policy Group (RSPG) recognizes the attractiveness of this spectrum for terrestrial mobile broadband services in its Opinion on Strategic Challenges facing Europe in addressing the Growing Spectrum Demand for Wireless Broadband [11], and notices the calls to reallocate the bands. However, the RSPG only considers the administrative reallocation of the spectrum after a withdrawal of the licences from the satellite operators, following actions from Member States for lack of compliance with the licence conditions:

> *In 2011, the Commission adopted Decision 2011/667/EU15 [12] on modalities for coordinated application of the rules on enforcement to an authorized operator of mobile satellite systems (MSS) in the event of an alleged breach of the common conditions attached to its authorization (launch of satellite, launch of commercial services, coverage, etc.). Subsequently, in late 2012*

Germany sent a notification of lack of compliance with the licence conditions to both authorised MSS operators which launched the step-by-step procedure at EU level.

The RSPG acknowledges the interest in this band for alternative uses, especially given the economic and social value of this spectrum, and recognises the on-going process, led by the COCOM MSS Working Group, regarding the EC Decision on coordinated enforcement action. In light of this, the RSPG recommends that ***if future actions taken by Member States related to Decision 2011/667/EU result in the withdrawal of licences, the Commission should consider re-allocation of the bands to terrestrial mobile services.***

An alternative proposal would be to strengthen the property rights regime of the satellite operators, liberalizing the bands by authorizing terrestrial-only use, and letting the satellite operators conclude wholesale agreements and/or spectrum leasing or trading with terrestrial operators.

The standardization process for terrestrial handsets in the mobile satellite bands has already started in the relevant standardization bodies (3GPP), following a request from Korean operators. Handsets are likely to become available, which will raise the value of the band for terrestrial operators, and facilitate the transactions between satellite and terrestrial operators.

Competition issues need of course to be addressed. The satellite operators will see a steep increase in the value of their spectrum through such a liberalization, and will benefit from a windfall gain. However, administrations have sufficient means to deal with such competition issues, for example by adjusting the spectrum fees that are attached to such liberalized spectrum licenses through administrative incentive.

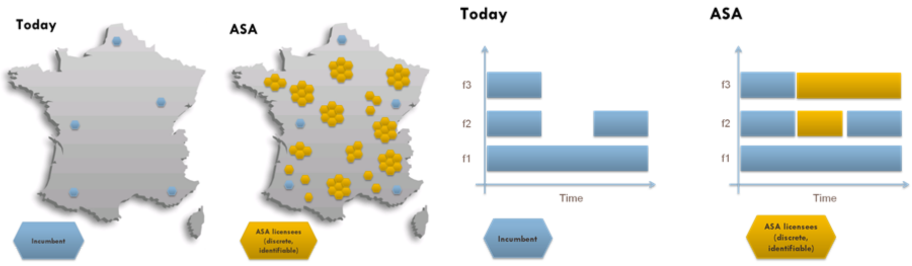
3.2.2 Licensed shared access

As mentioned in the introduction, spectrum management often segregates different radiocommunications services (mobile, fixed, broadcast) into different spectrum bands. In addition, governmental users are operating on different bands as commercial users, most of the time. This makes the spectrum management easier, as it avoids interference between different services and users. It results however in an underutilization of the resource as the spectrum is not used in all places at all times, as shown in figure 2.

Based on this finding, a number of proposals have been made to improve the spectrum management and sharing between different users, some of them are based on opportunistic access to spectrum without individual rights (wi-fj, TV white spaces, ...), while other proposals are based on the introduction of dynamic and flexible individual authorizations.

One of the proposals for dynamic and flexible individual authorizations is

Figure 2: Authorized shared access



called "authorized shared access". It was originally proposed by Qualcomm and Nokia and has been studied from an economical perspective in a working paper (Nicita, Parcu, Rossi, Ferrari Bravo, Corda 2013),[22].

According to the proposed ASA arrangement, band sharing would not be static and it would probably involve some compensation to the incumbent user in exchange for some quality of service (QoS). The ASA model contains a spectrum repository, a database with the relevant information on spectrum use by the incumbent (in the spatial, frequency and time domains). It may add safety margins and deliberate distortions to the actual use data in order to mask the true activity of the incumbent, which may be desired in the case of governmental users.

The model also contains an ASA Controller which computes the spectrum availability based on rules built upon ASA rights of use and information on the incumbent's use provided by the repository. The ASA Controller may be managed by the Administration, the NRA, the ASA licensee(s) or a trusted third party.

The conditions (i.e., when and how) under which the ASA spectrum can be subject to an economic transaction between interested parties.

ASA differs from the unlicensed model (wi-fi, "white spaces", *etc*) in that the channel borrowers would be *limited in number*, licensed and subject to sharing rules included in their rights of use. Under the wi-fi or "white spaces" rules, there are no negotiations with incumbents and the number of opportunistic users is unlimited and their identities unknown, which for some increases concerns about possible interference and the practicality of tackling them.

This concept has also drawn the attention of the Radio Spectrum Policy Group who renamed it "licensed shared access" (LSA) in their draft opinion on the issue. The RSPG defines the LSA concept as follows [13]:

> *"A regulatory approach aiming to facilitate the introduction of radiocommunication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incum-*

bent users. Under the LSA framework, the additional users are allowed to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorized users, including incumbents, to provide a certain QoS".

LSA applies to an incumbent, being any current holder of spectrum rights of use (commercial or governmental). However it is likely that the LSA concept has more relevance in practice when the incumbent user(s) and the LSA "licensee" are of different nature and subject to different regulatory constraints. It is envisaged that initially major opportunities for application of the LSA concept would be in the case of an incumbent being a governmental user.

Shared use of spectrum is a way to increase the amount of spectrum resources available for communication services and related uses. Previously segregated spectrum could be used more efficiently by better exploiting part of this resource that may be underutilized. Technical conditions should be harmonized, as far as feasible, in order to be able to develop adequate standards and equipment, and to achieve economies of scale.

From an economical point of view, the ASA/LSA approach has the potential to significantly decrease the transaction costs between commercial and governmental users. Currently such spectrum sharing between governmental and non-governmental is prohibited in most cases; when it is allowed, it is very difficult to find out which part of the spectrum is used in which places, and to determine the exact availability.

4 Conclusion

In this paper we have first reviewed the relevant theory of property rights in economics, developed from the seminal paper of Ronald Coase on *the Federal Communications Commission* [14]. Coase himself recognized that market transactions are *"often extremely costly, sufficiently costly at any rate to prevent many transactions that would be carried out in a world in which the pricing system worked without cost."* [15] and he was therefore cautious about the conclusions on the relative efficiency of property rights as compared to administrative allocations.

This discussion should not be taken to imply that an administrative allocation of resources is inevitably worse than an allocation by means of the price mechanism. The operation of a market is not itself costless, and, if the costs of operating the market exceed the costs of running the agency by a sufficiently large amount, we might be willing to acquiesce in the malalloca-

tion of resources resulting from the agency's lack of knowledge, inflexibility, and exposure to political pressure.

The theoretical part alone does not provide a definitive answer on the relative efficiency of administrative allocations and allocations that result from market transactions.

In the second part of the paper we have developed a number of recent examples, where property rights did play a role in finding an efficient solution to interference problems, as well as potential opportunities for efficient re-allocation of spectrum to higher-valued uses. We highlighted that the property rights theory did play a role in solving some interference situations, both involving a low and high number of affected parties. These solutions did not explicitly refer to the property rights theory, but were taken implicitly. We also noticed that some cases would benefit from a strengthening of the property rights for current users of the spectrum, to facilitate market transactions for an efficient re-allocation of the spectrum. Such alternatives based on property rights are sometimes omitted from the spectrum policy debate, unfortunately, as it is the case in the mobile satellite example. In our last example we consider that the new concepts which are being developed have the potential to considerably lower the transaction costs and therefore make the market more efficient. These concepts should definitely be taken into account when developing a new spectrum policy based on increased sharing, alongside the alternative proposals of opportunistic spectrum use without individual authorizations based on technological advances.

The problem confronting the users of the radio spectrum today is pretty much the same as the one stated by Coase more than fifty years ago:

> *The problem confronting the radio industry is that signals transmitted by one person may interfere with those transmitted by another. It can be solved by delimiting the rights which various persons possess. How far this delimitation of rights should come about as a result of strict regulation and how far as a result of transactions of the market is a question that can be answered only on the basis of practical experience. But there is good reason to believe that the present system, which relies exclusively on regulation and in which private property and the pricing system play no part, is not the best solution.*

A framework without property rights and a pricing mechanisms is likely not be the most efficient system for the management of a scarce resource. The authors believe that the European spectrum policy will greatly benefit from a more systematic use of property rights and a pricing mechanism in spectrum management. The aim of an efficient spectrum policy should be to create institutions that minimize the inherent transaction costs, the cost of searching information and negotiating.

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