

The Problem of Interference in Wireless Communications: The U.S. Regulatory "Solution" and the Property Rights Alternative

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Resumen

En EE UU, el problema de interferencia en las comunicaciones inalámbricas se resuelve mediante un sistema de planificación central, creado hace casi ocho décadas. Este mismo sistema es aplicado en la mayoría de países que permiten inversión privada en el sector telecomunicaciones. Un análisis breve de cómo este sistema surgió en EE UU y cómo opera, revela su enorme ineficiencia. El uso de derechos de propiedad en el espectro radioeléctrico produciría resultados eficientes, no solo en la asignación de frecuencias a servicios que tengan mayor valor, sino también en la solución de litigios sobre interferencias. Los casos de Guatemala y El Salvador, países que adoptaron derechos de propiedad en el espectro radioeléctrico, ilustran los beneficios de adoptar esta alternativa. Entre 1997 y 2001, el tráfico en telefonía móvil en estos dos países creció a una tasa anual mayor al doble que el promedio latinoamericano y más de doce veces la del Perú. Los latinoamericanos harían bien en dejar el viejo sistema de planificación central usado en EE UU y adoptar, en su lugar, un sistema de derechos de propiedad en el espectro radioeléctrico.

Abstract

The problem of interference in wireless communications was addressed in the U.S. by a command and control system instituted nearly eight decades ago. This system is currently applied in most countries that allow private investment in wireless communications. A brief analysis of how this system emerged in the U.S. and how it operates reveals its gross inefficiencies. An alternative approach based on property rights would be efficient not only in the allocation of frequencies to its highest value use, but also in solving interference disputes. The cases of Guatemala and El Salvador, two adopters of this approach, illustrate the benefits of the latter system. Between 1997 and 2001, the annual growth rate of mobile telephony traffic in these two countries more than doubled the average for Latin America and was over 12 times that of Peru. Latin Americans may benefit substantially by abandoning the current command and control system modeled after the U.S. and embracing the property rights approach.

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INTRODUCTION

Unlike other resources such as water, gas or oil, in the United States (U.S.) there is no system of property rights in the radio frequencies (also called radio spectrum). The government specifies what frequencies should be used for what services and then awards licenses for the provision of those services. With no price system to allocate radio frequencies, the outcome is inefficient. This article describes the system for licensing wireless communications used in the U.S. along with its related regulation of interference. It then proceeds to illustrate the system using the case of the FM radio service. The inefficiency of this approach is exposed and the alternative system of property rights is explained in detail along with an economic analysis of legal disputes. Finally, the case of Guatemala, a country that instituted a system of property rights on radio frequencies, is reviewed.

1. A BRIEF HISTORY OF INTERFERENCE REGULATION IN THE U.S.

Early in the 20th Century, radio communications were unregulated, and thousands of amateur broadcasters transmitted their signals across the air (de Sola Pool 1983: 111-2; Coase 1959). As the number of broadcasters increased, the U.S. Department of the Navy, one of the main users of radio for point-to-point communications (i.e. ship to ports, or ship to ship) urged the U.S. Congress to regulate radio communications (Coase 1959). In 1912, the U.S. Congress passed the Radio Act which required private radio operators to be licensed by the U.S. Department of Commerce (*Ibid.*). As the number of licensed radio stations increased, so did interference and the U.S. Department of Commerce found it necessary to impose operating restrictions. These restrictions were challenged. A set of Court decisions between 1923 and 1926 limited the discretion of the Secretary of Commerce in the process of issuing licenses. The courts ruled that licenses should be awarded to anyone requesting them as long as they broadcast within the designated frequency band¹. Without clear defined property rights, the stage was set for a textbook case of the tragedy of the commons. The period that followed is known as the "chaos in broadcasting". The number of radio stations multiplied. This time, the incumbent broadcasters cried for regulation (Hazlett 1990). In 1927, the U.S. Congress passed the Federal Radio Act which created the Federal Radio Commission, the regulatory body for the radio industry. The Commission was empowered to allocate frequencies to specific types of services, set the technical standards for equipment, define interference standards, set limits to transmission

1. In *Hoover v. Intercity Radio Co.* (1923) the court decision held that the Secretary of Commerce had no discretion to refuse a license. In *United States v. Zenith Radio Corp.* (1926) the court held that the Secretary of Commerce cannot assign frequencies or impose any restrictions other than what is already in the Radio Act (Coase 1959).

power, etc. Regulation left ample room for discretion, and licenses were only to be transferred with the Commission's prior authorization (Coase 1959). The government effectively seized property of the radio spectrum. Later in 1934 the Federal Communications Commission (known as the FCC) was created to take over the duties of the Federal Radio Commission and was made also responsible for the regulation of the telephone and telegraph industries (Coase 1959). The Communication Act of 1934 clearly prohibits private ownership of the radio spectrum; section 301 states:

It is the purpose of this chapter, among other things, to maintain the control of the United States over all the channels of radio transmission; and to provide for the use of such channels, but not the ownership thereof, by persons for limited periods of time, under licenses granted by the Federal Authority.

In 1951 while still a student at the University of Chicago Law School, Leo Herzel wrote an article critical of the Federal Communications Commission regulation of TV broadcasting², and proposed auctions to grant the rights to use radio frequencies (Herzel 1951). Building on Herzel's proposal, Coase (1959) proposed a system of rights for the radio spectrum. Coase did not see any difference between interference problems arising from radio stations transmitting in close proximity and, for example, the nuisance problems that may arise from a noisy neighbor, or say a polluting firm near a town. Should my neighbor have the right to play his or her music at full volume or should I have the right to silence? Should a cement plant have the right to emit pollutants to the air or should the inhabitants of a nearby town have the right to clean air? As Coase explained in his seminal article, *The Problem of Social Cost*, the problem is symmetrical in nature (Coase 1960). Giving the right to play music at full volume to my neighbor imposes a cost on me. Giving me the right to silence imposes a cost to my neighbor. If transaction costs are zero, bargaining between my neighbor and I will produce an efficient result, that is, society's welfare will be maximized. With positive transaction costs, giving the right to the least cost avoider maximizes society's welfare (Demsetz 1972; Calabresi and Melamed 1972). Nuisance problems are resolved every day in the Courts, and Coase proposed to use the same system for interference problems. The proposal (as was the case with Herzel's) was received with great skepticism³.

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2. "The inadequacy of the concept of the FCC as a policeman, only regulating to avoid traffic congestion in the frequency channels, was revealed by the history of the Act of 1912. The most important function of radio regulation is the allocation of a scarce factor of production, i.e. -frequency channels. The FCC has to determine who will get the limited number of channels available at any one time. This is essentially an economic decision, not a policing decision" (Herzel 1951).
 3. In 1959, Ronald Coase was asked to testify at FCC's hearings on the future of broadcasting. After he finished his arguments in favor of property rights for radio frequencies, Commissioner Phillip S. Cross opened the questions and asked: "Are you spoofing us? Is this all a big joke?" (Coase 1998). Another incident occurred when Coase was invited by the Rand Corporation to help prepare a report on problems of radio frequency allocation. As one may expect, the report proposed a market solution and was circulated within the Rand Corporation. The comments were so critical that

The story however, leaves unanswered the question of why property rights did not emerge as the solution to the interference problems. Hazlett (1990, 1998) provides ample evidence that this was the natural result of interest groups that benefited from the regulatory solution. As profitable uses for the radio spectrum were discovered by broadcasters, *de facto* rights were created. With free licenses awarded by the government, the early broadcasters benefited from a zero-priced resource. At the same time, the grantors of licenses and members of the U.S. Congress benefited from choosing a regulatory solution:

market transfers are screened by federal authorities; license renewals are less than costless or riskless; new spectrum use for broadcasting is prohibited by law. The system has transferred net resources to incumbent broadcasters, broadcast regulators (including oversight congressional committees), and advocates of the 'public interest' (Hazlett 1990: 172).

Since those days, the licensing system in the U.S. has evolved. It has increasingly allowed flexibility on the transfer of licenses, on the type of services permitted, or on the technology used, thus strengthening the rights of licensees (Webbink 1987, Shelanski and Huber 1998)⁴. In 1993, the U.S. Congress authorized the FCC to award licenses through auctions (See Federal Communications Commission 1997a). While auctions insure that licenses are awarded to those that value them the most, it still keeps a licensing system that only weakly resembles one of property rights.

2. THE LICENSING SYSTEM FOR WIRELESS COMMUNICATIONS IN THE U.S.

The FCC manages the radio electric spectrum by a command and control system in which specific services (i.e. FM radio, UHF TV, cellular telephony, etc) are allocated to pre-established frequency ranges. Once the service and technical standards are established, the FCC awards licenses to private firms (Webbink 1987).

The first phase of the licensing system is known as "block allocation". In this phase, the FCC allocates frequency bands for specific services: broadcast TV, FM radio, PCS mobile telephony, etc. The FCC then specifies technical standards for equipment and interference

the report was left unpublished (Coase 1998). For an exchange between Leo Herzel and Prof. Dallas Smythe; see Coase (1959).

4. If one thinks of property as an array of entitlements, then property becomes a continuous rather than a discrete concept. In this sense as more flexibility is granted to licensees, their rights are strengthened. This however, does not mean that licensees have full rights; they have only weak rights. They cannot transfer licenses without FCC

protection requirements. In addition, it specifies the geographic area in which the license is valid, ownership restrictions, license transfer procedures, etc. Thus, licenses provide only a weak bundle of rights. Firms are basically given a fixed set of parameters to conduct business. The rigidities in this command and control system lead to large inefficiencies (Hazlett 2001: 22-35). Kwerel and Williams (1992: 86) estimated that only in the city of Los Angeles reallocating 6 MHz from UHF-TV spectrum to wireless telephony would result in \$783 million of net social gain. The present licensing system prohibits this.

Typically the FCC initiates actions leading to a block allocation after receiving petitions from firms wanting to establish a new service. At its discretion, it will issue a document called Notice of Inquiry (NOI) or a Notice of Proposed Rule Making (NPRM) by which the FCC basically says "this is what I am thinking of doing, what do you think?". This sets in motion a long process by which comments are sought from the interested parties, the industry, and the general public. Replies and more comments may follow (Hazlett 2001: 27-8). It may include "hearings" in which interested parties explain to the FCC commissioners and staff the benefits of having the proposed service, the technical characteristics, interference specifications, technology, etc. This process may take several years (*ibid.*, pp. 40-2, 103-4, 120, 158). Once the FCC has made up its mind, it may issue another document called a Report and Order. In this document, the FCC provides a full specification of the new service, describes the rights the licensees will possess, what the licensee can and cannot do, the technical standards, the frequency band assigned, the mechanism to allocate licenses, etc. Typically, interested parties will initiate another round of comments and replies and the FCC may issue further reports amending the rules of the new service. At this point the second phase starts which consists of the assignment of licenses to service providers.

The magnitude of the current inefficiencies is large. Hazlett (2001: 158) estimates it took the FCC between 16 and 21 years to complete the two phases for the licensing of cellular telephony providers in the 1980s⁵. Even with the use of auctions to assign licenses, the process has taken between five and nine years for Personal Communications Service (Hazlett 2001: 120). With some minor variations, and more or less transparent procedures, this same system of licenses (and interference regulation) is applied in most countries where private firms are allowed to provide wireless communication services.

authorization, they cannot subdivide the band of frequency assigned and, with few exceptions, they cannot use the licenses for a different service than specified (See Shelanski and Huber 1998).

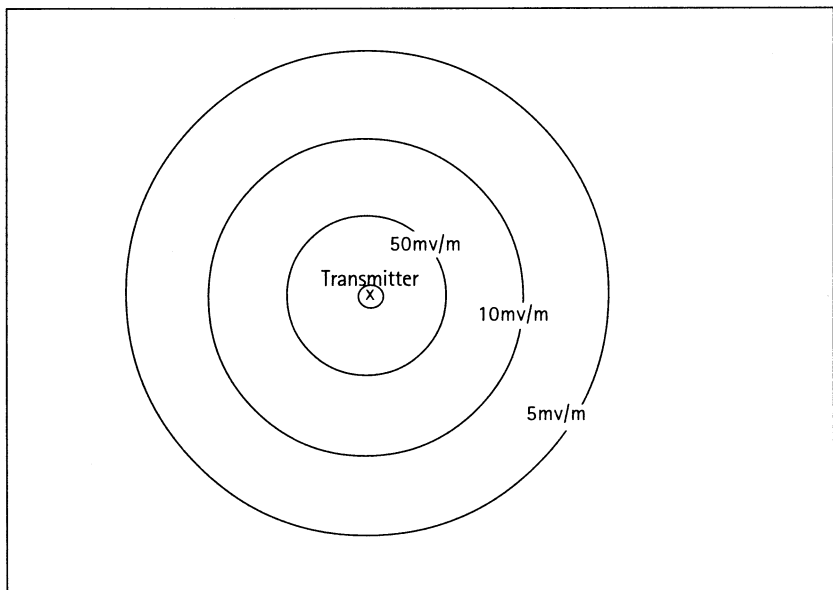
5. For a fascinating recount of this episode, see Calhoun (1988: 45-58, 122-32).

3. INTERFERENCE REGULATION IN THE U.S.

A summary of the way in which the FCC solves the interference problem in wireless communications will help understand the particular challenges of defining property rights for radio frequencies.

Radio signals are emitted by use of a transmitter and antenna. These radio waves are then intercepted by a receiver's antenna, filtered to discard unwanted signals, and then processed to recover the information superimposed on the transmitted signal. For good communication to occur, the received field strength of the desired signal must be greater by a technically specified amount than the received field strength of all undesired signals (De Vany *et al.* 1969). For a given radiated power and antenna height, the signal strength declines the more distant we are from the transmitter. To illustrate this, one can imagine circles around a transmitter. Each circle is called a signal contour. Each signal contour represents a given signal strength⁶, with inner circles representing higher signal strength and outer circles weaker signals (see figure 1).

Figure 1
Signal contours and signal strength



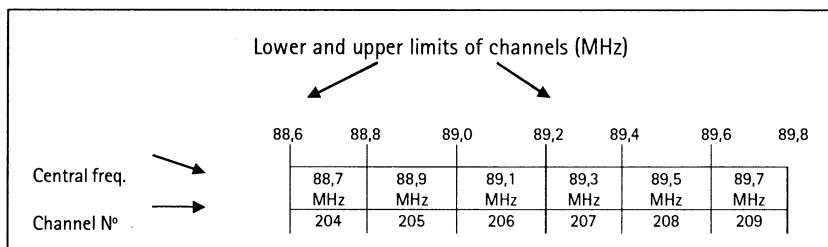
6, Signal strength is measured in millivolts per meter (mv/m) or volts per meter (v/m).

By changing the transmitter power and antenna height we can achieve the same signal strength at a given geographical location. As radio signals are spread in all directions and cannot be confined to a given geographical area and to some extent, neither into a given frequency, the potential for interference arises. This problem could be dealt with by regulation or by assigning adequately defined property rights.

I will use the FM radio service as an example to illustrate how interference problems are solved by means of regulation. The same physical and engineering principles apply to interference regulation of other services such as cellular telephony, TV broadcast, etc.

To avoid interference between radio stations, the FCC requires stations to be separated far enough from each other in geographic and frequency space. To illustrate this, let us take the case of FM radio service. The FCC allocates the frequency range (or band) of 88-108 MHz for FM radio. The FM band in turn is subdivided in 100 channels each 200 kHz wide⁷. We can represent part of the FM band as in figure 2.

Figure 2
Illustration of six channels in the FM band



Assuming we have one radio station in each of the six channels shown (channel 204 to 209), then the station in channel 204 (88,7 MHz) is said to transmit in a first adjacent channel to the station in channel 205 (88,9 MHz); it also transmits in a 2nd adjacent channel to the station transmitting in channel 206 (89,1 MHz), and so forth. Had there been two stations transmitting in the same channel, we would say that the stations transmit in a co-channel. To simplify the application of interference regulation, the FCC categorizes FM stations in eight classes based on their signal's strength at a given distance

7. FM channels are numbered from 201 to 300. "FM Table of Allotments". 47 CFR 73.202 (Oct. 1, 1999).

from the transmitter⁸. Based on the class of station, the FCC has standardized the required distance separation for stations transmitting in the same channel (co-channel), in one adjacent channel, and in second or third adjacent channels. For example, if a new Class A station wants to transmit in the same channel as an existing Class A station, regulations require it to locate at a distance of 115 km away. If it wants to transmit on a first adjacent channel, regulations require it to locate 72 km away. Alternatively, it could transmit in a 2nd or 3rd adjacent channel and locate 31 km away⁹.

The FCC interference regulation is extremely conservative. As Hayek (1945) pointed out, without a price system to allocate scarce resources, it is a futile task for any central planning agency to try to allocate resources efficiently. Buy using engineering standards with no relation to market preferences and a price system, the FCC permits a smaller than optimum amount of interference between broadcast stations¹⁰. The case of the so-called "short-spaced" FM stations (stations not complying with required distance separation) provides evidence of the conservative standards adopted by the FCC. In the 1997 Report and Order by the FCC on Short-spaced FM stations, the Commission cited a study by the National Association of Broadcasters that estimated a total of 312 FM radio stations broadcasting on 2nd and 3rd adjacent channels to other stations without adhering to the minimum distance requirements. These commercial stations have operated for decades without complaints by other broadcasters, thus indicating that harmful interference is not present when violating the actual FCC standards (Federal Communications Commission 1997b).

4. THE EFFICIENCY OF PROPERTY RIGHTS TO SOLVE INTERFERENCE DISPUTES

The first issue which must be faced by any legal system is one we call the problem of 'entitlement'. (...). The fundamental thing that law does is to decide which of the conflicting parties will be entitled to prevail. The entitlement to make noise versus the entitlement to have silence, the entitle to pollute versus the entitlement to breathe clean air.(...). These are the first order of legal decisions,... (Calabresi and Melamed 1972: 1090).

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8. Classes of FM stations: A, B1, B, C3, C2, C1, C0, and C. Each class of station is associated to a certain maximum power and antenna height. These parameters determine the coverage area of the station [Source: FCC, FM Station Classes and Service Contours (Nov. 7, 2000) <http://www.fcc.gov/mmb/asd/fmclasses.html>].
 9. FCC, *FM Station Separation Standards (Section 73.207)*. (April 16, 2001) (<http://www.fcc.gov/mmb/asd/spacing/73207.html>).
 10. A study by Prof. Theodore Rappaport from Virginia Polytechnic Institute explains that the conservative nature of the FCC separation rules is due to the fact that they were established when older technology made FM radios more susceptible to drift, adjacent channel capture, and adjacent channel overloads than in modern FM receivers (Rappaport *et al.* 1999: 3, 6, 43-5, 47).

A bundle of rights –also called entitlements– could be protected by property rules, liability rules or inalienability. Our focus in this article is on the first two. A key difference between property and liability rules is the concept of consent for mutually beneficial exchange, and the transaction costs to obtain consent (Calabresi and Melamed 1972). No one can take entitlements protected by property rules unless the holder sells them willingly at a price at which he agrees to sell. On the other hand, entitlements protected by liability rules could be taken as long as the taker provides compensation in an amount established by the courts (*Ibid.*). Thus, consensual exchange is governed by property rules while non-consensual exchange is governed by liability rules. In general, when transaction costs are low, property rules maximize society's welfare, while if transaction costs are high, then liability rules should be favored by the courts (Calabresi and Melamed 1972; Demsetz 1972). The case of interference in radio signals could be dealt by using these same rules¹¹. For example, let us assume that two broadcasters face a problem of interference and that a system of property rights on spectrum has been established. If the holder of frequency rights detects that signals from another broadcaster have trespassed his space, he could sue and obtain relief by injunction (an application of property rules) or remedies (an application of liability rules) from the trespasser by showing that the harm is substantial and that the interference is unreasonable. Now the problem of what is reasonable or unreasonable arises if the rights on radio frequencies are not clearly specified. Unlike the more straightforward land rights, radio signals present some particular characteristics that are addressed in the following section.

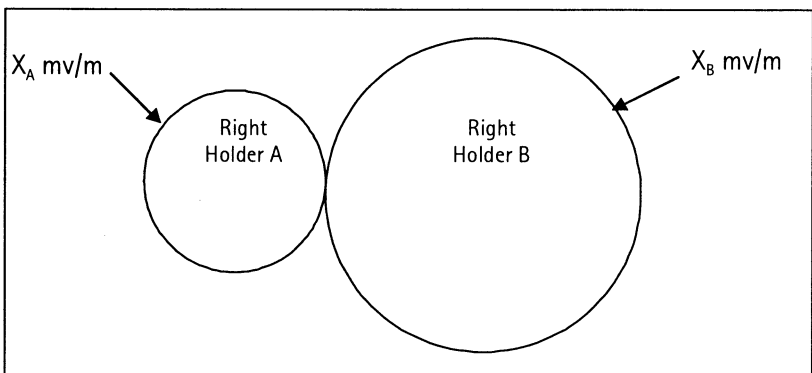
4.1 Defining the Rights on Radio Frequencies

The use of a property rights approach to solve the problem of interference requires the clear definition of these rights. Following De Vany *et al.* (1969), the rights on radio frequencies should be defined in three dimensions: (1) the time during which communications occur; (2) the geographical area over which radio signals are spread; and (3) the frequency range in which radio signals are transmitted. The system of rights needs to specify the limits within which the rights-holder is allowed to spread his signal into adjacent areas, otherwise harmful interference will occur. This could be done by specifying a maximum signal strength of X mv/m at the boundary of the rights-holder's area. Figure 3 illustrates this. Two signal contours at the boundary of each area are drawn, one representing a strength of X_A millivolts per meter, and the other a strength of X_B millivolts per meter. The actual geographical areas need not be circular, they could have a square or hexagonal shape or any other which does not leave empty spaces between adjacent areas. Radio

11. This is irrespective of whether the country is a common law or a civil law country.

signals not only spill over adjacent geographical areas but also into adjacent frequencies. Thus, the rights need to specify a maximum allowable field strength (Y mv/m) in adjacent frequency bands. Admittedly, this system needs somebody to define these limits. In principle, this could be done by the Courts, industry organizations, the industry regulator, or any other entity. For example, when the government of Guatemala granted property rights in radio frequencies in 1996, the former regulator took the task to set these standards (Ibarguen 2001). For this system to work efficiently, rights-holders should be able to subdivide their entitlements in any three dimensions of time, geographical area, or frequency dimension. Thus, a rights-holder should be able to lease his rights for certain hours a day, or lease his rights in a certain part of his area of service, or in a certain portion of his frequency band. In similar way, rights-holders should be allowed to aggregate service areas or aggregate frequency bands (De Vany *et al.* 1969). Rights-holders should be granted complete freedom to choose the technology and type of service for which his frequencies would be used. A system of rights registration, similar to land titles, would need to be established for the proper functioning of a market for tradable rights. Interested parties should be able to consult freely the availability of frequencies in desired areas and to identify the owners of frequencies. In Guatemala the former regulator assumed also this role (Ibarguen 2001). Once the system of rights is established, interference disputes could be handled by private negotiations or by the courts. The important thing to keep in mind is that property rights incorporate the price mechanism by which resources are allocated efficiently. As the next section shows, this efficiency extends into the way courts solve these disputes about rights.

Figure 3
Limits to signal strength at boundary of geographical areas



4.2 Economic Analysis of Interference Disputes

The efficiency of the property rights system to resolve interference problems could be illustrated by a simple example. Let us assume that there are two radio stations; one of them -the plaintiff- has been operating for several years; the other station -the defendant- started broadcasting recently. Assume the plaintiff alleges that the new station (the defendant) is causing harmful interference¹². The courts can either use property rules or liability rules to solve this dispute.

Let us assume a simple case of unilateral care under a negligence rule. Most likely a court will use bilateral care, but for ease of presentation let us adhere to the unilateral care. Unilateral care means that only the defendant (i.e. the injurer) can exercise care to reduce interference, and thus it is the only party liable for damages. The negligence rule states that the new station (the defendant) can avoid liability if it complies with the signal strength limits defined in its rights (the X mv/m and Y mv/m explained before). If the defendant is found negligent, then it will pay the expected damages to the old station.

Let us assume that the new station could take measures to abate interference by reducing its signal strength. This imposes a cost on the new station as lowering its signal strength reduces its coverage area, and in turn, its revenues from advertising. On the other hand, increasing its signal strength above the limits specified in its rights not only increases interference with the old station, but also increases its coverage area in the opposite side, as shown in figure 4.

Following Miceli (1997: 16-20) let us assume that the cost of interference abatement to the new station is $c(x)$, a continuous function decreasing with its signal strength (figure 5). Let us assume that $D(x)$ represents the expected damages the defendant would need to pay to the old station if found negligent. The expected-damages function is assumed to be continuous and increasing on the defendant signal's strength (figure 5). Note that as signal strength increases, so does interference. The optimal solution to society is to minimize the cost of avoiding interference plus the expected damages:

$$\text{Minimize: } c(x) + D(x) \qquad \text{with respect to } x$$

12. It is important to mention that signal strength could be affected by ionospheric and meteorological conditions some of which are random in nature. Thus, even if the rights-holders had calibrated their equipment properly, it is possible that inadvertently their signal strength may increase above the limits specified in their rights.

Figure 4
Coverage area according to signal strength

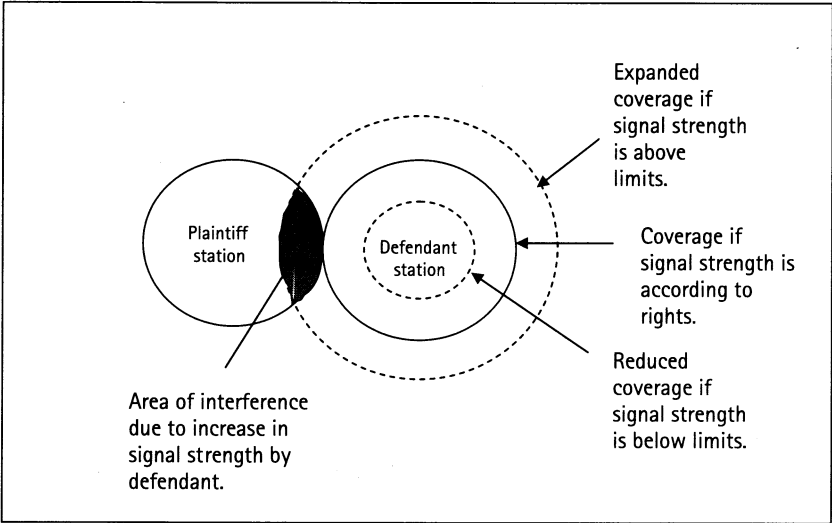
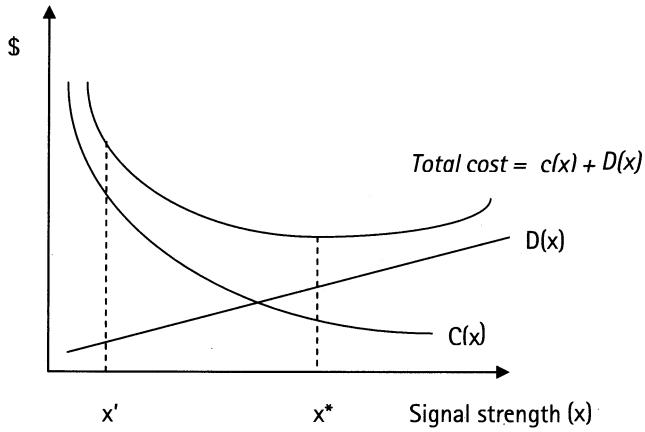


Figure 5
Defendant's optimal level of signal strength with negligence rule (unilateral care)



Note: x^* = optimal interference standards; x' = conservative interference standards
 $C(x)$: Defendant's cost of interference abatement
 $D(x)$: Expected damages for which the defendant would be liable

The first order condition is:

(1)

Solving this results in an optimal level of signal strength x^* . Assuming that the due standard of signal strength was set optimally at x^* , therefore the new station avoids liability by insuring that its signal strength (x) is equal to or lower than x^* . In this case, the cost to the new station is $c(x)$. If the new station is found negligent ($x > x^*$), the cost to it would be $c(x) + D(x)$. Thus, the optimization problem for the new station is to minimize the following:

$$\begin{array}{lll} c(x) & \text{if} & x \leq x^* \\ c(x) + D(x) & \text{if} & x > x^* \end{array} \quad (2)$$

By solving the first order condition we get: $x = x^*$, which is also optimal for society. Notice that the negligence rule causes a jump (the discontinuity at $x = x^*$) in the total cost to the new station (the defendant). This induces the new station to behave optimally by setting its signal strength at or a fraction below x^* . Note also that the efficiency of the property rights approach does not depend on the due standards of care which are set by the courts or by any other entity. If due standards are chosen conservatively at $x' < x^*$ allowing very little interference (figure 5), then it is optimal for the new station (the defendant) to pay damages and increase its signal strength to $x^* > x'$, where the sum of its abatement cost plus damages: $c(x) + D(x)$ is minimized. Operating at a signal strength equal to x' will be inefficient. Thus, even if standards differ from optimal, the negligence rule would produce efficient outcomes. This is the great advantage of property rights over regulation¹³. Now let us review briefly the case of Guatemala, a country that has applied the property rights approach to the radio spectrum.

4.3 Guatemala's Experience Using Property Rights on Spectrum

At the end of 1996, the General Law of Telecommunications was enacted. It instituted a system of property rights for the radio spectrum giving rights-holders ample freedom to use the assigned frequencies for whatever service they deemed convenient, to use the technology of their preference, and to sell, subdivide or lease their spectrum rights (Hazlett

13. Note that the Courts could choose to use property rules instead of liability rules. In this case the plaintiff could obtain relief by injunction or may decide to buy the defendants' rights to radio frequencies. If transaction costs are low, the parties will bargain until the efficient outcome is achieved.

2001: 167-8; Ibarguen 2001). The law permits any interested party to request frequencies as long as they were not already taken, and set a tight timeframe and simple procedures for the assignment of user rights to the spectrum. For example, the regulator was required to answer any request for frequencies within 3 days.

For the adjudication of frequencies, the regulator was given 10 days (Ibarguen 2001). The law also stipulated that user rights would be auctioned only in cases of competing claims. Otherwise, they will be granted freely for a period of 15 years. The timeframe for scheduling the auction was set at 35 days after a period in which opposing parties were allowed to file comments with the regulator (*Ibid.*). The regulator also established a registry of radio frequencies which is open for public consultation so that interested parties can know who owns what. This reduces transaction costs and facilitates the use of valuable spectrum to those that value it the most. Ibarguen (2001) reports that most disputes are settled privately; indeed the Guatemalan Association of Broadcasters has set up an arbitration office to settle disputes. The same association has acquired sophisticated equipment to monitor interference and help resolve disputes, thus lowering transaction costs.

All these changes woke up the sleepy cellular market in Guatemala. From having one cellular operator between 1989 and 1997, Guatemala ended with four wireless telephony operators in 2000. The growth of wireless telephony has been spectacular both in Guatemala and in El Salvador; a country that also implemented a liberal system of property rights on the radio spectrum a year later¹⁴. In 1997 average mobile penetration in Latin America was more than three times that of Guatemala and El Salvador; by 2001 this gap had narrowed dramatically (see table 1) despite the higher income of most Latin American countries. Peru's modest growth in this period signified that the gap with the Latin American average has widened. Even more important, the growth of total traffic in mobile telephony minutes in the period 1997-2001 for Guatemala and El Salvador outpaced largely the average for Latin America, and by more than 12 times that of Peru. No doubt this has produced a massive increase in consumer surplus in El Salvador and Guatemala dwarfing the progress achieved in other Latin American countries.

14. Hazlett (2001: 170) reports a political event in El Salvador that may hinder the future of the system of property rights in the radio spectrum in that country. To be sure, private property is constantly violated in less developed countries. However, influential individuals or firms find somehow ways to protect to a more or less degree their property. There is no reason to think that spectrum rights would be different.

Table 1
Indicators of mobile telephony growth and competition

	Annual growth rate of mobile telephony traffic 1997-2001 (%)	Mobile penetration 1997 (%)	Mobile penetration 2001 (%)	Herfindahl- Hirschman Index (2001)
Latin America	45,4	2,1	14,3	5.571
Peru	8,2	1,7	5,9	4.865
Guatemala	104,6	0,6	9,7	3.038
El Salvador	103,1	0,7	12,5	3.378

Note: Latin America includes Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, and Venezuela.

Source: Traffic data is from Pyramid Research. Mobile Penetration is from ITU's *World Telecommunications Indicators 2002*. Herfindahl-Hirschman Index was constructed using subscriber data of mobile operators from Pyramid Research, and data from national telecommunications regulators' websites.

A simple calculation provides a rough estimate of the gain in consumer surplus experienced in Guatemala. Assuming a linear demand function for the period 1997-2001, the increase in consumer surplus is approximated by:

$$\Delta CS = (Price_{1997} - Price_{2001}) \left(\frac{Traffic_{1997} + Traffic_{2001}}{2} \right) \quad (3)$$

Using data from Pyramid Research on revenue per minute as a proxy for price, and minutes of mobile voice telephony, the gain in consumer surplus is US\$ 352 million. Equally distributing this amount along the four-year period, the annual gain in consumer surplus is US\$ 88 million, about 0,5% of gross domestic product. The gain to society is even higher as this result does not include changes in producer surplus, nor does it include benefits to consumers of fixed line telephony due to higher competition in mobile telephony¹⁵.

The increased competition due to the adoption of property rights in the radio spectrum in Guatemala and El Salvador is also evident in the lower Herfindahl-Hirschman index (table 1), a measure of industry concentration that reflects the ability of new firms to enter the mobile telephony market without interference of government restrictions. Indeed, by controlling how much spectrum to license, governments in other countries effectively

15. To some degree, mobile telephony is a substitute for fixed telephony to many consumers. Thus, declines in mobile telephony prices should be accompanied by declines in fixed telephony prices. Between 1997 and 2001, the average revenue per minute (a proxy for price) of mobile telephony declined 67 percent. No doubt this must have depressed prices in fixed telephony services.

control the amount of competition. By doing so, they impose enormous losses in consumer welfare to its citizens. The property rights approach transfers these decisions to the market.

CONCLUSION

By using property rights, the problem of interference in radio frequencies could be solved efficiently. Under a property rights system, the regulatory agency or any other entity would need to have a centralized registry of rights to radio frequencies. Such a system could resemble real estate or vehicle property registries. Spectrum rights require the careful specification of the right-holder's signal characteristics defined in the three dimensions of time, geographic area, and frequency. In addition, they need to specify the maximum signal strength allowable on the boundaries of the right-holder's area. Efficient outcomes would result even if the rights set conservative limits in signal strength. The cases of Guatemala and El Salvador implementing a property rights approach has resulted in large increases on consumer welfare that dwarf the progress made in other Latin American countries that followed the U.S. model of regulation.

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