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SPECTRUM PRICING ASSESMENT IN THE 2.6 GHZ FREQUENCY BAND FOR LONG TERM LEASE

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ABSTRACT

In this paper, an analysis of secondary spectrum market for an OFDM based technology is performed. The potential transactions between three different operators (entrant, medium and incumbent) are considered in three different scenarios: urban, suburban and rural. Based on their business models over a period of ten years, the maximum and minimum prices are estimated for each transaction. Results show that the incumbent operator is the more likely buyer/lessee of spectrum, due to its large number of costumers, and the entrant operator is the potential seller/lessor. This, in addition of the economic benefit, would allow the incumbent to access more spectrum, since regulation authorities usually limit the amount of spectrum an operator can access at the auctions, and softens at the same time the business model of the entrant operator, which can find an additional source of revenues for the early stages of the project.

Index Terms—techno-economic analysis, secondary spectrum market, spectrum pricing

1. INTRODUCTION

The wireless communication industry has considerably increased recently. More and more mobile broadband services are demanded so that spectrum has become even a more valued resource. This relative shortage of spectrum in addition to the lack of flexibility and inefficiency of the current administrative methods for spectrum management, has given rise to a reform process of radio spectrum policy. This reform focuses mainly on the introduction of flexibility through the liberalization based on technological and services neutrality, and the establishment of a secondary spectrum market (see, for example, [1] and [2]).

Since 1995 a critical review of the traditional model for spectrum management has been carried out by numerous authors, who propose basically three alternative models, which should be optimally combined in order to achieve the maximum benefits. The first of them is a market mechanism based model which would allow efficient use of spectrum, but at the same time suffer from risks like spectrum fragmentation [3], monopolization and speculation [4]. Secondly, the development of new technologies which allow automatic control of interferences would turn the model based on exclusive rights unnecessary [5] [6], what could steer the model towards a common use model. However, this model also presents drawbacks as the doubtfully economic feasibility.

Therefore, concepts like *Cognitive Radio* or *Dynamic Spectrum Allocation* (DSA) has

concentrated a considerable amount of the research as an alternative third model able to combine the advantages of the others. Dynamic Spectrum Allocation refers to network centric approach, where the decision is made by the network, while Cognitive Radio is a terminal-based approach [1]. Many different algorithms have been proposed for both techniques, i.e. [7]-[9], but they are in all cases based on an *instantaneous* approach, i.e. the bandwidth assigned to each operator depends on its instantaneous traffic demand, although they all experience the busy hour simultaneously. The authors of [10] make a comparison about the benefits provided by the different mechanisms (auction, direct trading and brokerage) for secondary spectrum trading in a long term view.

Nonetheless, in a secondary spectrum market scenario, the whole analysis performed in this area considers the cognitive users or an entrant operator as the buyer/lessee, and an incumbent operator with an excess of spectrum resources, the potential sellers/lessors. As it is discussed below, there are also circumstances in which an entrant might lease spectrum to an incumbent operator and they both can get economic profit from the transaction. The incumbent operator might need more bandwidth to serve all its customers, while the entrant operator, which has a lower number of customers, can lease spectrum in its startup phase.

Spectrum pricing represent a quite complex problem which has been studied in different works [11]-[14]. Diverse methodologies have been proposed to estimate the commercial value of spectrum for mobile communication services, among which it is worth highlighting benchmarking [12] and expected value of the project [12][13]. The first estimates the price of spectrum through a comparison with the price paid for the same or similar frequencies in other countries. The second one considers the spectrum as any other economic resource whose value is provided by the sum of the net present value of the cash flows of the project. In this paper, the second approach is used. In CDMA networks other methods have been proposed [15][16] that consider the reduced spatial coverage because of the decrease in spectrum or the generated interference.

The purpose of this paper is to propose a techno-economic model that let assess long-term potential transactions between different operators in a secondary spectrum market for an OFDM based system as well as a method to estimate the prices of these transactions. The model is based on the total network-related cost of roll-out obtained by combining the dimensioning results of an OFDM-based 4G system model and an economic model. The analysis here is performed taking as a premise that the spectrum transaction must make economic sense. This means that a buyer will only buy spectrum if the costs of deploying its radio access network with the spectrum it already had plus the spectrum bought is lower than the cost of deploying without this extra bandwidth. The same reasoning is applicable to the seller: it will only sell spectrum if the increase in costs, i.e. due to an increase in the BS density, is lower than the benefits obtained by the transaction.

The paper is organized as follows. Section 2 reviews the techno-economic and system model of the OFDM-based 4G system considering market assumptions such as the demand, as well as technical aspects. Section 3 presents the secondary market pricing methodology as well as the scenarios considered, the involved agents, i.e. different kinds of mobile operators, and the circumstances that must occur for a transaction to happen. Section 4 shows the main results

and discussion about the feasible spectrum trades between the operators, which are based on the network cost decrease they may have because of the increase of available spectrum. In relation to these costs, prices that could be paid for the licenses in this secondary market are estimated.

2. TECHNO-ECONOMIC AND SYSTEM MODEL

An OFDM-based 4G system model and a techno-economic model for wireless access networks has been combined to dimension the whole access network (from macro BS up to the IP aggregation network) for purely macro cellular networks, and to assess the total network-related costs that would be required in a specific operator environment. More specifically, the case of study is an operator provisioning ubiquitous voice and broadband data services in the urban, suburban and rural areas of a western European country.

A. Market Assumptions

The demand side of a techno-economic model is often recognized as the critical factor that requires assumptions as reliable as possible. As a consequence, we have based our assumptions in a realistic scenario, based on Italy, and lessons learnt can also be applied to other “big” western European countries such as France, Spain, UK or Germany. The whole country is divided into three geographic areas (urban, suburban and rural areas), based on [19], with the following population shares: 19.4%, 27.2% and 53.4%, respectively. The area occupied by each of the geographic areas is: 0.6%, 5.5% and 93.9%, respectively.

Table 1. Parameters for service dimensioning.

<i>Parameters</i>		<i>Mobile communication customer</i>	<i>Mobile broadband customer</i>
<i>Mobile broadband service</i>	Minimum downlink data rate (guaranteed in 70% of cell area)	1 Mbps	1 Mbps
	Minimum uplink data rate (guaranteed in 70% of cell area)	330 Kbps	330 Kbps
	Download data cap	300 Mbytes	3 Gbytes
	Yearly growth rate of download data cap	5%	5%
	Uplink to downlink busy-hour (BH) data traffic ratio	20%	20%
	Proportion of daily traffic in the busy hour	10 %	10 %
<i>Voice services (VoIP)</i>	Average voice traffic per subscriber (busy hour)	200 mE	--
	Yearly growth rate of voice service demand	5%	--
	Voice call data rate ITU-T/G.729A	24 kbps	--
	Blocking probability for telephony traffic	0,5 %	--

Two target markets have been considered: the mobile communication market, where customers use voice and data services via mobile handsets, and the mobile broadband market, where a broadband Internet access service is provided using modem devices. The former market is characterized by having already reached very high penetration levels (from 123% of the 1st year (Y1) to the 137% of the 10th year (Y10)) while the latter one is still an emerging market (a penetration increasing from 6% in Y1 to 41% in Y10 has been assumed based on the current average penetration in Western Europe (6%) and the projection of forecasted data provided by [20]).

Three different operators are considered: an entrant, a medium size and an incumbent operator with market shares described below in section 3. Finally, service traffic is calculated based on assumptions about service demand detailed in Table 1.

B. System Model

A complete description of this model can be found in [17]. It is worth mentioning that the frequency band intended to be used is 2.6 GHz, the reuse factor is 3, spatial diversity MIMO 2x2 is applied and different bandwidths have been considered.

Concerning the cost model, obtaining an exact prediction of the deployment costs of a wireless cellular network is difficult as a consequence of the many different aspects that affect the results. To deal with this complexity, the per-unit investments and operating costs assumed in this paper are based on the costs of other well-known technologies, such as WiMAX or UMTS and on prices provided by operators, manufacturers and national regulatory authorities. In order to calculate total network-related costs, operating expenses and annualized investments are obtained from the per-unit cost assumptions and the network dimensioning solutions following the formulas provided in [17]. After estimating the yearly costs, a discounted cash flow model is applied to account for both investments and running costs assuming a commercial discount rate of 15%.

3. SPECTRUM PRICING METHODOLOGY AND CONSIDERED SCENARIOS

This section presents a methodology that let us illustrate the possibilities that a secondary spectrum market offers to the different operators.

A. Methodology

The general assumption made for the trading in this secondary spectrum market is that operators that have a set of radio spectrum frequencies are willing to obtain the maximum economic benefit. This economic profit can be achieved in two different ways. Firstly, by using all these radio spectrum resources in the roll-out of their mobile network, which they use to provide the communication services, in order to decrease the cost of the roll-out, increasing therefore the economic benefit (the larger the bandwidth per sector used in the network roll-out, the lower the network costs, considering invariable the rest of assumptions). Secondly, they could make available a subset of their radio spectrum resources in the secondary spectrum market. This strategy would have economical sense if there were another operator willing to pay for that subset of frequencies a price higher than the additional cost assumed by

the seller/lessor operator as a consequence of the lower bandwidth used in its network. Likewise the buyer/lessee operator would only pay that price if the cost savings in the roll-out of its own network with higher bandwidth per sector is higher than that price.

The methodology is based on the comparison of the prices that the seller and the buyer are willing to accept considering the radio spectrum supply and demand, depending on the the roll-out costs.

1) Radio spectrum supply

An operator A with a total bandwidth X_A MHz/sector would be willing to make available in the secondary spectrum market an amount of Y MHz/sector for a price higher than the increase of network costs associated with the roll-out with a maximum of $(X_A - Y)$ MHz/sector instead of with X_A MHz/sector.

Therefore, the minimum price for the spectrum will be: *“Network roll-out costs with $(X_A - Y)$ MHz/sector” - “Network roll-out costs with X_A MHz/sector”*.

2) Radio spectrum demand

An operator B with a total of X_B MHz/sector would be willing to acquire in the secondary spectrum market an amount of Y MHz/sector for a price lower than the network cost saving associated with the roll-out with a maximum of $(X_B + Y)$ MHz/sector instead of with X_B MHz/sector.

Therefore, the maximum price for the spectrum will be: *“Network roll-out costs with X_B MHz/sector” - “Network roll-out costs with $(X_B + Y)$ MHz/sector”*.

The transaction of this Y MHz/sector between the operator A and B would only happen if the maximum price set by the spectrum demand is greater than the minimum price set by the spectrum supply. The final transaction price would be in the range defined by these minimum and maximum prices being farther or closer from the average price depending on how the negotiation process occurs between the buyer/lessee operator and the seller/lessor operator.

The estimation of these minimum and maximum prices in the different cases to simulate (for the three kinds of operators, four possible spectrum assignments and three geographical areas) is based on the calculation of the net present value after ten years. Since the revenues of the different operators are considered constant independently of the total spectrum bandwidth used in the roll-out, the difference between the net present values in the different cases (network roll-out with different spectrum bandwidth) determines the difference in network roll-out costs.

B. Scenarios

Different kinds of mobile operators are going to be considered in the secondary market transactions of spectrum. These different operators represent cases that are or will be present in the mobile communication market providing mobile communication services and mobile broadband access. They differ from each other in their market share and consequently, they

will have a demand for more or less bandwidth making the transactions of radio spectrum resources among them very likely.

The operators considered in our study are:

- *New entrant*. Its market share increases from 1% in the first year to 20% in the 10th year.
- *Medium operator*. A medium operator with a market share increasing slowly from 15% in the first year to 19% in the 10th year.
- *Incumbent*. An incumbent operator with a market share falling from 30% in the first year to 26% in the 10th year.

In addition to that, different spectrum assignments are going to be considered for each of the mobile operators. More specifically:

- A total of 15MHz, corresponding to 5MHz per sector.
- 30 MHz, corresponding to 10MHz per sector.
- 45 MHz, corresponding to 15 MHz per sector.
- 60 MHz, corresponding to 20 MHz per sector.

All spectrum assignments are defined in terms of bandwidth per sector taking into account that a factor of reuse of 3 is considered.

As it can be observed, all these combination of operators and assignments cannot happen at the same time in the 2.6 GHz frequency band. However, as some of them could happen, it is interesting to explore all different combinations.

Finally, the study is going to be carried out separately for each of the geographic areas: urban, suburban and rural areas. The reason to do that is that each of these areas has their own specific characteristics in terms of the amount of radio spectrum resources needed for the roll-out of the networks, the requirements that make the business case profitable, etc. making advisable to do a study for each one. The results of applying the proposed methodology to the scenarios above are presented next in section 4.

4. RESULTS

This section presents the results obtained by applying the methodology for pricing the spectrum in the secondary market, which has been defined in section 3. Although the results have been obtained for the 3 types of operators, 4 possible spectrum assignments and three geographical areas, only the most interesting are shown here.

The OFDM network deployment considers 100% coverage after 10 years for urban, suburban and rural areas.

A. Urban and suburban areas

As it was explained in section 3, when the secondary market model was detailed, the seller would only give spectrum up if it is paid higher than the increase in its network costs. This represents the minimum price for the spectrum. Similarly, the maximum price a buyer would pay is the decrease of its network costs due to the larger amount of spectrum. These two values define a range for possible values of the transactions. The closeness to one or the other depends on the negotiation process of the two involved parts. As an example, the values for the potential transaction in urban scenario, where the seller is the new entrant with 20 MHz/sector, are represented in Figure 1. Mean prices are marked with a triangle and minimum and maximum prices are noted. These values are also shown in Table 2.

Table 2. Minimum, average and maximum prices (in M€) considering a new entrant as a seller/lessee operator in urban areas.

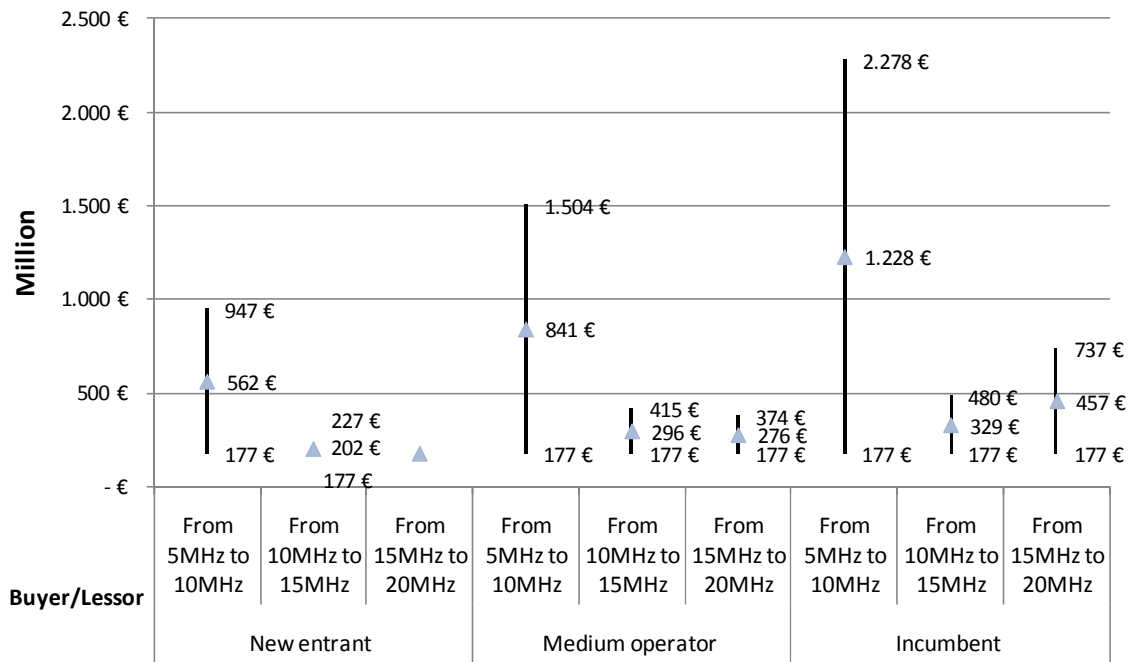
Buyer		Seller: New entrant (15 MHz/sector to 10)			Seller: New entrant (20 MHz/sector to 15)		
		Max	Mean	Min	Max	Mean	
New entrant	5 to 10MHz/sector	226.6	946.6	586.6	177.1	946.6	561.8
	10 to 15MHz/sector	226.6	226.6	226.6	177.1	226.6	201.9
	15 to 20MHz/sector	*	*	*	177.1	177.1	177.1
Medium operator	5 to 10MHz/sector	226.6	1,503.9	865.3	177.1	1,503.9	840.5
	10 to 15MHz/sector	226.6	415.5	321.0	177.1	415.5	296.3
	15 to 20MHz/sector	226.6	374.3	300.4	177.1	374.3	275.7
Incumbent	5 to 10MHz/sector	226.6	2,278.3	1,252.5	177.1	2,278.3	1,227.7
	10 to 15MHz/sector	226.6	479.9	353.3	177.1	479.9	328.5
	15 to 20MHz/sector	226.6	736.8	481.7	177.1	736.8	456.9

The results show that the entrant operator is a leading candidate to give up spectrum. The smaller number of customers to be served implies a network roll-out with a smaller density of base stations (as compared to the network of the other operators). Since they are not really capacity constrained networks, the rise in costs suffered by selling/leasing spectrum are lower than the savings earned by other operators.

Table 3 shows the mean prices for all potential transactions. The largest cost savings occur when moving from 5 MHz/sector to 10 MHz/sector. As a result, virtually in all cases, an operator with a 5 MHz/sector spectrum assignment would be willing to find some operator with more than 10MHz/sector willing to give up 5MHz/sector. Moreover, in those cases the acquisition of additional 5MHz/sector means making the business model viable since with 5 MHz/sector the NPV is negative for all the operators. For the same reason, operators with an assignment of 10MHz/sector are the least prone to participate in the secondary spectrum market as a seller/lessor.

Therefore, an operator should have at least 15 MHz/sector available to be willing to sell 5 MHz/sector in the secondary market. Since the entrant operator has the lower market share, it will be the most likely to resell spectrum.

Figure 1. Minimum and maximum prices considering a new entrant with 20 MHz/sector as a seller/lessor



The analysis for suburban areas shows that the players of most of the potential transactions are an operator with an assignment of 20MHz/sector as a seller/lessor and an operator with an assignment of 5MHz/sector as a buyer/lessee, like in an urban scenario. However, the prices for the potential transactions are lower, as it is shown in Table 4. The prices (normalized to the deployment area) of potential suburban transactions are between 7% and 23% of the prices for urban transaction when the new entrant operator is the seller/lessor. Results are similar (6%-23%) for the other cases.

Table 3. Potential transactions of 5 MHz/sector in urban areas and their average prices in M€

Seller / Lessor		<i>Entrant</i>			<i>Medium</i>			<i>Incumbent</i>		
Buyer / Lessee		<i>10- 5 MHz/sec</i>	<i>15-10 MHz/sec</i>	<i>20-15 MHz/sec</i>	<i>10- 5 MHz/sec</i>	<i>15-10 MHz/sec</i>	<i>20-15 MHz/sec</i>	<i>10- 5 MHz/sec</i>	<i>15-10 MHz/sec</i>	<i>20-15 MHz/sec</i>
<i>Entrant</i>	<i>5-10 MHz/sec</i>	947	578	562	681	660		713	842	
	<i>10-15 MHz/sec</i>		227	202						
	<i>15-20 MHz/sec</i>			177						
<i>Medium</i>	<i>5-10 MHz/sec</i>	1225	865	841	1504	960	939		992	1.120
	<i>10-15 MHz/sec</i>		321	296	1504	960	939			
	<i>15-20 MHz/sec</i>		300	276		415	395			
<i>Incumbent</i>	<i>5-10 MHz/sec</i>	1612	1252	1228	1891	1347	1326	2278	1379	1.508
	<i>10-15 MHz/sec</i>		353	329		448	427		480	
	<i>15-20 MHz/sec</i>		482	457		576	556		608	737

Table 4. Comparison of average prices of the transactions (in €/MHz/Km²) between suburban and urban areas

Seller / Lessor		<i>Entrant</i>		
Buyer / Lessee		10- 5 MHz/sec	15-10 MHz/sec	20-15 MHz/sec
<i>Entrant</i>	5-10 MHz/sec	20%	21%	18%
	10-15 MHz/sec		24%	17%
	15-20 MHz/sec			9%
<i>Medium</i>	5-10 MHz/sec	21%	21%	20%
	10-15 MHz/sec		23%	19%
	15-20 MHz/sec			6%
<i>Incumbent</i>	5-10 MHz/sec	20%	20%	19%
	10-15 MHz/sec		23%	19%
	15-20 MHz/sec			7%

B. Rural Areas

The detailed results for rural areas are shown in Table 5. The main difference from previous cases is that, in this case, most of transactions involve an operator with an assignment of 10MHz/sector as a buyer/lessee. The reason is that the cost saving associated with growing from 15MHz/sector to 20MHz/sector are very low as a consequence of the lower traffic level present in the rural areas compared with that of urban or suburban areas. For the same reason, in almost all cases, an operator with 20MHz/sector in a rural area would be willing to supply 5MHz/sector in the secondary market. Moreover, this case considers the possibility that the operator does not deploy any network since it does not make profit. Therefore,

Table 5. Potential transactions of 5 MHz/sector in rural areas and their average prices in M€

Seller / Lessor		<i>Entrant</i>			<i>Medium</i>			<i>Incumbent</i>		
Buyer / Lessee		10- 5 MHz/sec	15-10 MHz/sec	20-15 MHz/sec	10- 5 MHz/sec	15-10 MHz/sec	20-15 MHz/sec	10- 5 MHz/sec	15-10 MHz/sec	20-15 MHz/sec
<i>Entrant</i>	5-10 MHz/sec	368		202			198			240
	10-15 MHz/sec	2.118	3.869	1.953	2.579		1.948	3.513		1.990
	15-20 MHz/sec			36			32			
<i>Medium</i>	5-10 MHz/sec	829		663	1.290		659			701
	10-15 MHz/sec	2.532	4.283	2.366	2.993	4.696	2.362	3.926	4.461	2.404
	15-20 MHz/sec						28			
<i>Incumbent</i>	5-10 MHz/sec	1.762		1.596	2.223		1.592	3.156		1.634
	10-15 MHz/sec	2.297	4.047	2.131	2.758		2.127	3.691	4.225	2.168
	15-20 MHz/sec			74			70			111

transaction from 10 to 0 MHz/sector is considered. Results show that both the medium size and the incumbent operators would be interested in buying/leasing 10 MHz spectrum to a new operator which would sell/lease it.

5. CONCLUSIONS

In this paper an analysis of secondary spectrum market has been made between three different operators, classified as incumbent, medium, and new entrant operators. The possible spectrum long-term transactions between these operators, which already own some spectrum, are assessed.

According to the results obtained by applying the methodology proposed, the largest number of potential transactions in the secondary market involves a new entrant as a seller/lessor and an incumbent operator as a buyer/lessee, because of their respective low and high market shares.

In general, the largest beneficiary of radio spectrum in the secondary market is the incumbent operator. The larger number of customers to serve makes it necessary a larger number of base stations. As a result, its cost saving associated with the access to a larger amount of spectrum per sector is the highest, because this extra spectrum allows larger cell range per base station, reducing the number of needed base stations. Hence, these operators would be the major applicants of additional radio spectrum. Similarly, the new entrant is a leading candidate to give up spectrum. The smaller number of customers to attend implies a smaller number of base stations in comparison with the network of the rest of operators. Leasing spectrum would be probably preferred to selling, thus, keeping the new entrant its options to further deploy the network.

This conclusion perfectly fits with reality, since the amount of spectrum that the operators can access in an auction is limited by the regulation authority due to competitive reasons. Therefore, the incumbent operator would probably like to buy more spectrum than it is allowed to, and as a consequence, it would be willing to buy more spectrum in the secondary market. On the other side, the entrant operator is allowed by the regulator to buy more spectrum than it might need at first, which it can use to improve its business model as an additional source of revenues at the early stages of the project.

The spectrum available and the zone of the deployment make also a difference with regard to the most probable transactions and their prices. In urban and suburban areas, the largest cost savings occur when the operator with access to less spectrum buys/leases spectrum. In rural areas, cost savings associated to growing from 15MHz/sector to 20MHz/sector are very low due to the lower traffic level compared with that of urban or suburban areas, making these transactions less likely.

The results show that the introduction of flexibility in spectrum management through the adoption of market mechanisms opens a secondary spectrum market which can bring economic benefits for both parts. This long-term transactions will be advantageous for entrant operators whose business case would soften, as well as for incumbent, which can satisfy their

demand at lower cost. This means an increase of the competition, which in turn benefit the users.

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REFERENCES

- [1] FCC. (2002). *Spectrum policy task force report*. ET Docket No. 02- 135
- [2] EC. (2005). Communication from the commission to the council, the European parliament and the European economic and social committee and the committee of the regions - A market-based approach to spectrum management in the european union. COM (2005) 0400 final.
- [3] RSPG opinion on wireless access policy for electronic communications services (WAPECS). (A more flexible spectrum management approach), 2005, RSPG05-102 Final.
- [4] La evolución de la gestión del espectro radioeléctrico, GRETEL 2007, Cátedra COIT.
- [5] E. Noam. Spectrum auctions: Yesterday's heresy, today's orthodoxy, tomorrow's anachronism: taking the next step to open spectrum access. *Journal of Law and Economics*, 1998, XLI, 765-790.
- [6] K. Werbach. Supercommons: Toward a unified theory of wireless communication, *Texas Law Review*, 2004, 863-973.
- [7] Salami, G.; Thilakawardana, S.; Tafazolli, R.; , "Dynamic Spectrum Sharing Algorithm Between Two UMTS Operators in the UMTS Extension Band," *Communications Workshops, 2009. ICC Workshops 2009. IEEE International Conference on* , vol., no., pp.1-6, 14-18 June 2009
- [8] Niyato, D.; Hossain, E.; , "Spectrum trading in cognitive radio networks: A market-equilibrium-based approach," *Wireless Communications, IEEE* , vol.15, no.6, pp.71-80, December 2008
- [9] Hong Xu; Jin Jin; Baochun Li; , "A Channel Portfolio Optimization Framework for Trading in a Spectrum Secondary Market," *Communications (ICC), 2010 IEEE International Conference on* , vol., no., pp.1-5, 23-27 May 2010

- [10] Hyenyoung Yoon; Junseok Hwang; Weiss, M.B.H.; , "Research on Secondary Spectrum Trading Mechanisms Based on Technical and Market Changes," *New Frontiers in Dynamic Spectrum*, 2010 *IEEE Symposium on* , vol., no., pp.1-12, 6-9 April 2010
- [11] K. van Bruwaene. Estimating the value of spectrum. EBU Technical Review.2003.
- [12] PWC and NZIER. Renewal of sapectrum rights for cellular services pricing methodology. Discussion paper for the ministry of economic review. 2006.
- [13] AEGIS and PLUM. Estimating the commercial trading value of spectrum. A report for Ofcom. 2009.
- [14] S.A. Azcoitia, M.A.M. Fernández and L.M.G. Verdura. Using bottom-up LRIC models to calculate radio spectrum value for mobile operators. Telecommunications Internet and Media Techno Economics (CTTE), 2010 9th Conference on, 1-7.
- [15] Al Daoud, A.; Alanyali, M.; Starobinski, D.; , "Secondary Pricing of Spectrum in Cellular CDMA Networks," *New Frontiers in Dynamic Spectrum Access Networks*, 2007. *DySPAN 2007. 2nd IEEE International Symposium on* , vol., no., pp.535-542, 17-20 April 2007
- [16] Al Daoud, A.; Alanyali, M.; Starobinski, D.; , "Pricing Strategies for Spectrum Lease in Secondary Markets," *Networking, IEEE/ACM Transactions on* , vol.18, no.2, pp.462-475, April 2010
- [17] A. Moral, J. Vidal, J. Pérez, A. Agustín, N. Marina and A. Høst-Madsen., "Techno-economic evaluation of cooperative relaying transmission techniques in OFDM cellular networks", *EURASIP Journal on Advances in Signal Processing*. Volume 2011, Article ID 5070035, 23 pages doi:10.1155/2011/5070035.
- [18] Italian statistics: ISTAT (Istituto nazionale di STATistica - <http://www.istat.it/istat/>)
- [19] FIREWORKS (2008): "Project Deliverable 1D3:FIREWORKS Business Model". 1D3-IST-27675 STP. Available at <http://www.ist-fireworks.eu>
- [20] Analysys Mason. Mobile and fixed broadband: co-habitation or competition.Webinar, 16 September 2008.
- [21] Moral, A. et al. "Project Deliverable 1d5: Report on Business Models". ICT-215282 STP ROCKET Project. Available at <http://www.ict-rocket.eu/deliverables.php>
- [22] IEEE 802.16 Broadband Wireless Access Group, "IEEE 802.16m system requirements", IEEE 802.16m-07/002r4, October, 2007