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## Conference Paper

# Introduction of dynamic spectrum management technologies: The role of industry openness and spectrum policy

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# Introduction of Dynamic Spectrum Management technologies: the role of industry openness and spectrum policy

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## ***Abstract***

The introduction of Dynamic Spectrum Management (DSM) has been challenged by several technical, economic and regulatory factors. This study analyzes market structure conditions in terms of industry openness and spectrum policy for introducing DSM technologies into mobile markets, developing a framework which combine System Dynamics modeling (top-down approach) and Bayesian network data analysis (bottom-up approach) for analyzing current mobile markets and their future evolutions possibilities. This model describes mobile-operator centric and end-user centric scenarios for a future DSM deployment.

**Key words:** Dynamic spectrum management (DSM); industry openness; spectrum policy; System Dynamics; Bayesian network; technology diffusion; end-user centric and mobile operator centric scenarios

## ***1) Introduction***

Dynamic Spectrum Management (DSM) aims to improve the spectrum efficiency by accessing dynamically the spectrum resources. The original concept was introduced by Mitola (2000) with the name of Cognitive Radio (CR). He suggested the idea of a radio frequency transceiver performing a cycle of activities, including “*observe, orient, plan, learn, decide and act*”. Many years later, ITU finally defined the main terms related to Dynamic Spectrum Management (DSM), such as Cognitive Radio System (CRS) and Software-Defined Radio (SDR) (ITU-R M.2225, 2011).

Despite large efforts in R&D, these technologies have not been successfully introduced into the mobile market. Several reasons have been identified for this slow deployment. A dynamic management of the spectrum involves in practice most of the telecommunication layers and players; and not only end user terminals as Mitola originally suggested. Moreover, different solutions for DSM are under discussion. In fact, several standards are currently under development, such as those related to IEEE and ETSI organizations. The IEEE Protocol for accessing white spaces (PAWS) standardizes the usage of spectrum database for accessing white spaces. On the other hand, ETSI Reconfigurable Radio System (RRS) is developing complementary standards focusing on a cognitive pilot channel proposal and a functional

architecture for a dynamic access of spectrum, based on Software Defined Radio (SDR)<sup>1</sup>. Finally, 3GPP has also standardized some functionalities aiming to better utilize the spectrum resources within the operator's network (e.g., LTE carrier aggregation). Thus, until the moment, there is no one single path for deploying DSM functionalities. Besides technology, many authors have claimed DSM needs a new spectrum regime. Besides what has been already pushed by regulators in around the world<sup>2</sup>, Medeisis & Minervini (2013) emphasized the need for a dedicated frequency band for dynamic spectrum access to enable technology efforts achieving the market. On the other hand, Holland et. al. (2012) introduced the need for a more flexible spectrum regime allowing a dynamic management of the interference.

In (Basaure et. al., 2012), we introduced the idea that mobile markets can be classified in terms of industry openness and spectrum decentralization to show the importance of a regulation evolution towards DSM technologies. This paper aims to analyze how the industry openness and spectrum policy affect the introduction of such technologies taking into consideration the main challenges mentioned above. We consider the deployment of DSM technologies in two possible opposite scenarios: end-user centric devices and mobile operator centric devices.

## 2) Literature review and definition of the problem

The market structure of the mobile telecommunications industry has a large impact on the diffusion of new technologies. Academic literature has analyzed the market structure of the mobile telecommunication industry from several perspectives. Some studies focus on vertical integration and its effect on competition. For instance, Howell, Meade and O'Connor (2010) studied the structure from a transaction economic perspective, concluding that competition between vertically integrated operators would induce more investment and competition than a vertical separation of the market. Kim et. al. (2011) studied the case of mobile virtual network operators (MVNOs), suggesting that while they increase competition in the mobile telecommunications industry, the mandated provision of access lowers the investment intensity of mobile network operators (MNOs). Other studies focus on critical mass<sup>3</sup> and diffusion perspective. Li & Lyons (2012) showed that the number of networks and the history of market structures affect the speed of service diffusion. They studied also the effect of market concentration, technology, standardization, privatization and independent regulation. Jang et. al. (2005) described that the pattern of diffusion of mobile telecommunications is characterized by an S-shaped curve; which varies its spread due to the magnitude of network externality. Mak & Zwick (2010) pointed out that in industries with network externalities, investment is profitable if total investment exceeds a critical mass. Grajek & Kretschmer (2012) identify critical mass as a function of installed base and price.

Additionally, spectrum regulation has emerged as an important topic for driving market competition and innovation. For example, Lundborg et. al. (2012) consider spectrum as an important production factor, having effect on the network cost and thus its asymmetric allocation can produce competition problems. Although market based spectrum allocation was suggested many years ago (Coase, 1959), in recent years this idea has emerged with strength due to new technological development. For example, Mayo & Wallsten

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<sup>1</sup> more information about radio reconfiguration architecture and interfaces for mobile devices: ETSI TS 103 146, ETSI TS 103 095

<sup>2</sup> As an example of a spectrum sharing policy we mention the Licensed Shared Access (LSA), driven by the CEPT ECC.

<sup>3</sup> a critical mass is the "minimum network size that can be sustained in equilibrium" (Economides and Himmelberg, 1995)

(2010) stated that policy effort towards a secondary market of spectrum is already having a positive impact on the mobile industry in the US and it will produce further gains in the future.

This paper analyzes how the market structure in terms of industry openness and spectrum policy affect the introduction of DSM technologies and the impact these technologies will have in different mobile markets.

### **3) Methodology**

This paper combines in its analysis top-down and bottom-up approaches. The bottom-up approach is used for analyzing the current data on market structure through Bayesian network analysis. The top-down approach analyzes the future impact of DSM technologies on different markets through System Dynamic modeling.

System Dynamics analyzes different organizational systems as a whole with the objective to understand their dynamic behavior, and the relations between different factors. We perform this approach based on previous models available in literature and assumption gotten from literature and from other sources. In order to correctly assess the modeling performed in the top-down approach, we support the main assumptions of this model with country data analysis, using a Bayesian network. While a System Dynamic modeling describes the relation of different variables within time, our Bayesian network describes the conditional probabilities between variables in one point of time. Thus, this paper uses a Bayesian analysis as an input for modeling the dynamic behavior of the whole system characterized by feedback loops between variables within time.

### **4) Market structure analysis for selected markets**

Market structure can be defined as the minimum set of variables that characterize a certain market. For example, the size, the number of players, the market concentration, the price level, technology requirements of the companies and the entry and exit barriers are part of this set. The structure of the market will determine the performance achieved by an industry. Some general market structure are e.g., oligopoly and perfect competition.

In this paper we characterize the mobile communication market by separating the variables affecting the spectrum policy and industry openness.

Industry openness is the level at which an industry is vertically disintegrated. Considering the Coase theorem<sup>4</sup>, vertical integration happens when the contracts costs are high enough because of high asset specificity, causing appropriable quasi-rent and giving room to individual opportunistic behavior. If the industry is open, the costs of contract will generally be lower than those of a vertical integration, since the asset became less specific and appropriable quasi-rent lower (Klein et. al. 1978). From another perspective, the openness of the industry can be defined by the entry and exit barriers. These barriers are those costs of a company entering or exiting the market and may explain, e.g. a high level of return of investment and a source for economies of scale (Demsetz, 1982).

This analysis considers the following variables to define the level of openness of the industry. Variables describing the level of investment and return of the industry: mobile average revenue per user (ARPU), cellular invest per capita (average performed by operators), investment as percentage of revenue (investment/ARPU). Variables describing the costs of the contract that the end users experience: churn rate

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<sup>4</sup> for example in: Coase, R. H.;1937. The Nature of the Firm, 4 *Economica* 386 (1937)

(monthly %), mobile price (average price of one minute in USD), mobile penetration (%), prepaid ratio (% from total subscription). Other variables explaining contract costs between companies on the industry: termination rate (in USD) and network operator - service operator separation (yes or no).

In addition to the industry openness, we consider in the spectrum policy those variables describing the mobile market that are related with the spectrum licensing and therefore with number of players, since spectrum is the main resource allowing the entrance to the market. The most relevant variables describing the spectrum policy are: regulator technology neutrality (yes or no, according to the law), market technology neutrality (yes or no, according to the market), spectrum concentration index (HHI<sup>5</sup>), market share concentration index (HHI), spectrum reselling rights (yes or no, the possibility of trading spectrum) and the number of mobile network operators (MNOs). Since spectrum is a heterogeneous resource, we use another variable to analyze the impact of the concentration in lower frequency bands (below 2.0 GHz); which are usually considered as more valuable for mobile operators.

The utilized Bayesian network was implemented with the help of BayesiaLab 5.1 software, which includes machine learning algorithm functionality. In a Bayesian network, each variable is represented by a node and the relation between nodes are described by an arc, which is built using conditional probabilities. A first network is built using an unsupervised structural learning (EQ algorithm), tuned by defining the temporal dependence between variables. A Bayesian network describes the causalities between variables and therefore it shows which variables are more suitable to describe the industry openness and the spectrum policy. Pearson correlation is described graphically by the color and thickness of the arcs (Figure 1 & 2). Blue color means positive and red means negative correlations. The thickness is proportional to the strength of the correlation. The force of the node describes the total relevance of a node (a variable) for explaining the complete structure represented by the graph.

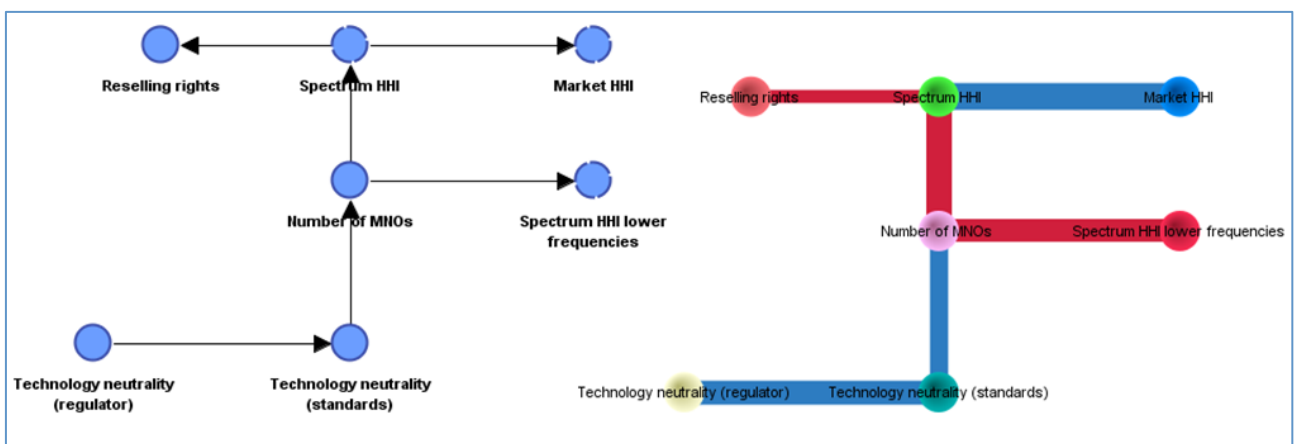


Figure 1: Spectrum policy variables and their causalities explained by a Bayesian network. (Left) Causal Bayes network; (Right) Pearson correlation.

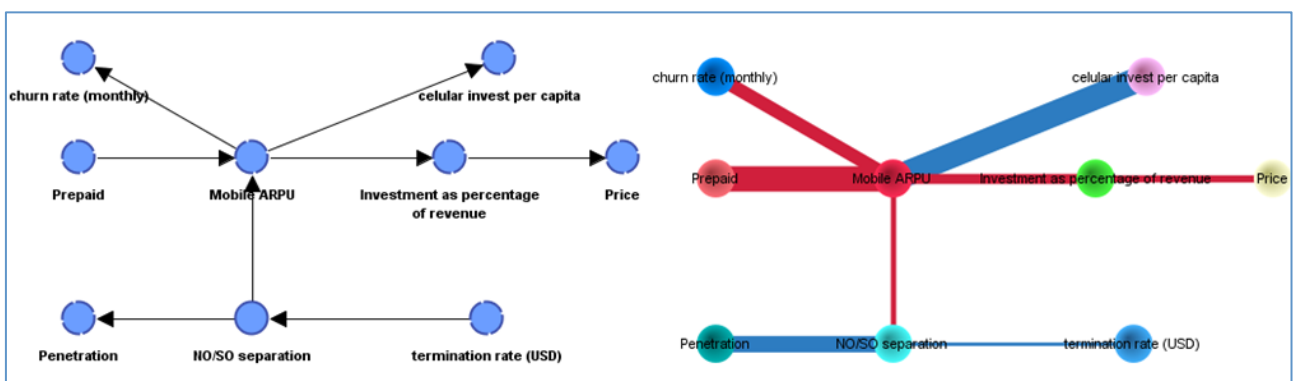
<sup>5</sup> HHI stands for Herfindahl - Hirschman Index

**Table 1: Relationship analysis and force of the nodes for Bayesian network of Figure 1**

Parent	Child	p-value	Pearson's Correlation	Node	Total Force
Number of MNOs	Spectrum HHI	1,62 %	-0,5794	Number of MNOs	1,8658
Number of MNOs	Spectrum HHI lower frequencies	1,78 %	-0,5131	Spectrum HHI	1,4998
Spectrum HHI	Market HHI	4,90 %	0,6068	Spectrum HHI lower frequencies	0,7341
Technology neutrality (standards)	Number of MNOs	1,16 %	0,414	Technology neutrality (standards)	0,6764
Technology neutrality (regulator)	Technology neutrality (standards)	0,20 %	0,5423	Market HHI	0,5104
Spectrum HHI	Reselling rights	4,19 %	-0,2964	Technology neutrality (regulator)	0,2875
				Reselling rights	0,2467

Figure 1 describes the causal relation between variables related to the spectrum policy from selected 24 countries<sup>6</sup> (OECD, 2011; ITU 2011; Wireless Matrix 2011). This model uses a confidence level of 95 % (p-values). The network shows the interdependences of different variables. First of all, the dependence between regulator technology neutrality and market technology neutrality is quite logical. Then, the number of operators is affected positively by the technology neutrality. Additionally, the number of operators affects negatively spectrum concentration; both lower frequencies and the whole spectrum. Finally, the market concentration is the final output of this network of variables, which is mostly affected by the whole spectrum allocation, the number of operators and technology neutrality. Spectrum reselling is more probably to happens with a lower spectrum HHI; however, we may assume that it still does not have a significant impact on the current mobile markets (p-value and correlation are low). Therefore, spectrum policy is best described by the market share HHI rather than the spectrum allocation. In future analysis, reselling rights should have an impact on the reallocation of spectrum and on the final market share HHI, but currently this is not the case. Therefore, for the purpose of this analysis, we define the spectrum decentralization index as follow.

$$\text{Spectrum decentralization index} \approx \text{market HHI}$$



**Figure 2: Market structure variables and their causalities explained by a Bayesian network. (Left) Causal Bayes network; (Right) Pearson correlation.**

<sup>6</sup> Australia, Austria, Belgium, Brazil, Canada, China, Chile, Czech Republic, Denmark, Finland, France, Germany, India, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States

**Table 2: Relationship analysis and force of the nodes for Bayesian network of Figure 2**

Parent	Child	p-value	Pearson's Correlation	Node	Total Force
Prepaid	Mobile ARPU	0,01 %	-0,6815	Mobile ARPU	2,9273
Mobile ARPU	celular invest per capita	0,05 %	0,6799	NO/SO separation	1,3275
NO/SO separation	Mobile ARPU	0,49 %	-0,1433	Prepaid	0,9480
Mobile ARPU	churn rate (monthly)	0,23 %	-0,3602	Investment as percentage of revenue	0,6653
termination rate (USD)	NO/SO separation	0,01 %	0,0920	celular invest per capita	0,5748
NO/SO separation	Penetration	0,04 %	0,4394	churn rate (monthly)	0,5017
Mobile ARPU	Investment as percentage of revenue	3,60 %	-0,2706	termination rate (USD)	0,4214
Investment as percentage of revenue	Price	6,29 %	-0,1934	Penetration	0,3530
				Price	0,3157

Figure 2 describes the causal relation between variables related to the industry openness from 37 selected countries<sup>7</sup> (OECD, 2011; ITU 2011; Wireless Matrix 2011). This Bayesian network has also a confidence level near 95%. The network shows that market structure may be best described by the price index and cellular investment per capita. Policy decisions such as termination rate and service/network operator separation affect the mobile ARPU and penetration levels. In addition, the prepaid ratio highly impacts the level of industry openness and therefore affects the mobile ARPU. The two main outcomes of policy decisions about the industry openness are price index and the investment level, which represent the incentives operators have given the characteristics of the industry. Churn rate describes end user behavior related to the operator. High churn rate are connected with lower ARPU levels and higher level of industry openness. However, churn rate variable seems to be characterizing the ARPU level rather than being a parameter for decision making (such as price and investment).

This analysis also indicates that regulatory decisions regarding bundling can be made at different levels: handset and network levels. Handset unbundling, described here by e.g., prepaid percentage, and industry unbundling, described by e.g., service and network operator separation. When regulator mandates unbundling at handset level, mobile ARPU decreases; along with the investment per capita. In addition, handset unbundling has a negative impact on the price level, as it shows the middle part of the network (from prepaid to price). At the industry level, a vertical separation decreases also price and investment levels. In brief, vertical integration affects positively the investment and price levels and vertical disintegration affects them negatively. These findings are also supported by previous literature (see section 2). Therefore, for the purpose of this analysis, we define the industry openness index as follows.

$$Industry\ openness\ index \approx \frac{1}{price\ index * celular\ investment\ per\ capita}$$

## 5) Analysis of mobile markets

This section performs a general analysis of different markets in terms of spectrum decentralization and industry openness.

Figure 3 describes OECD markets based on their reported data (OECD Communication Outlook, 2011). Checking different countries we realize that Japan represents a closed industry while Finland represents an

<sup>7</sup> Australia, Austria, Belgium, Brazil, Canada, Chile, China, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States

open industry. In addition, New Zealand has a centralized spectrum (despite its effort for allowing spectrum property rights) while UK has a decentralized spectrum.

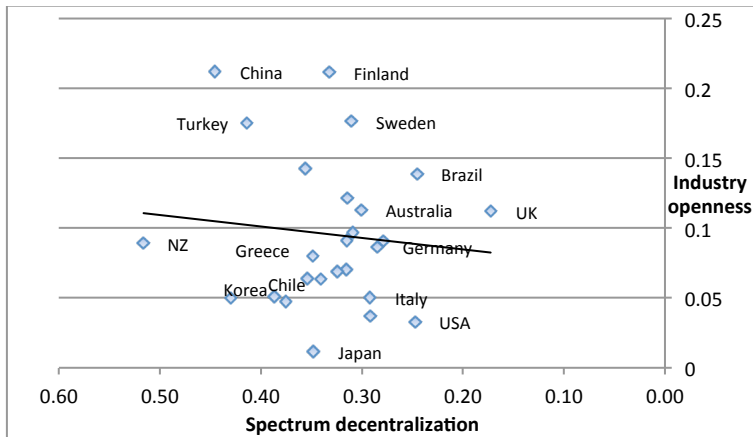


Figure 3: location of selected markets based on OECD data (2011)

Figure 4 and 5 describe the evolution of selected mobile markets in terms of spectrum decentralization and industry openness. This data was obtained from ITU Yearbook Statistics (ITU-D, 2012) and Global Wireless Matrix (2011). From Figures 3, 4 and 5 we can determine that these two axes do not correlate and can be analyzed independently.



Figure 4: mobile market evolution 2004-2011 in terms of spectrum decentralization and industry openness (ITU 2012, Global Wireless Matrix 2011).

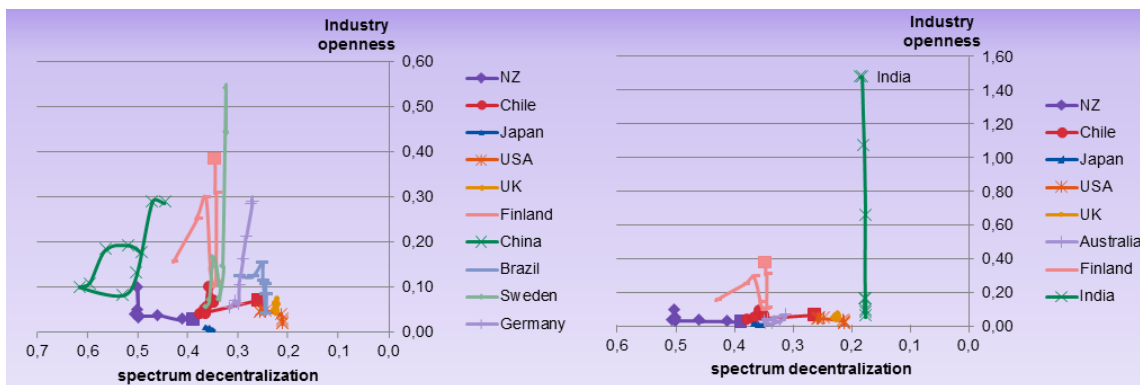


Figure 5: mobile market evolution in terms of spectrum decentralization and industry openness (ITU 2012, Global Wireless Matrix 2011). (Left) selected markets without India, (Right) selected markets including India.



## 6) System approach for understanding the introduction of DSM technologies

This section utilizes a system dynamic approach to analyze the introduction of DSM technologies.

The academic literature usually characterizes the introduction of mobile network technologies with network effect and critical mass, described by an S-shape diffusion curve. For instance, Michalakelis et. al. (2010) uses the Bass diffusion model to explain the dynamic diffusion of network technologies, considering the substitution effect and an increasing saturation level. Another relevant work (Kim & Kim, 2007) studied the diffusion patterns of IP-based services, network-based services and durable goods. They realized that late take-off phenomenon involved in the diffusion of network technologies (and explained by network externalities) is not involved in the newly introduced IP-based services.

We can recognize two important elements. The first is the network effect, in which a technology needs a critical mass to successfully reach a dominant design and compete against another technology. A second element is the substitution, where a newer technology replaces an older one.

In a competition between two homogeneous networks, under high network externalities, the winning network will grow into a less than social equilibrium, which depends on the initial condition (Hayashi, 1995). In addition, network effect is higher when the success depends on the compatibility with other external factors. For example in DSM, the end user terminals need a critical amount of spectrum available for sharing, other end-user centric terminals in the market and service providers offering dynamic spectrum to successfully dominate against mobile operator centric solution.

Other way of understanding a competition between two technologies is a substitution model, in which a new technology competes against an older technology of a saturated market. Technology substitution has been successfully modeled by the Lotka-Volterra equations by utilizing the so called predator-prey competition model. Lotka-Volterra describes the competition of two species for a common resource and explains survival, extinction and coexistence of technologies.

Both network externalities and predator-prey models explain how DSM technologies diffusion may happen. We apply them by using a system dynamic approach as shown in Figure 6.

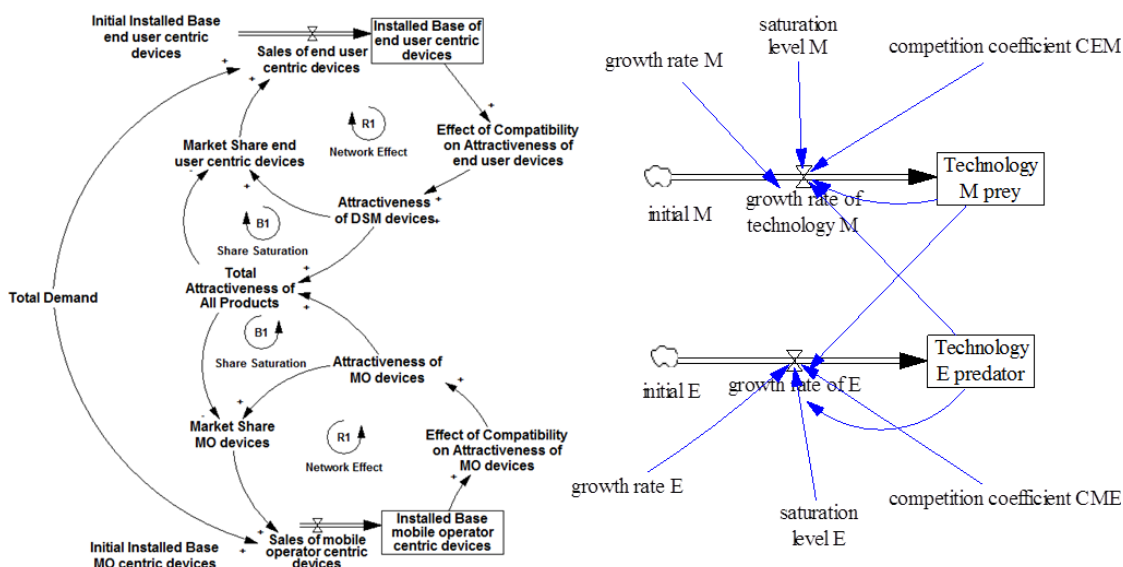


Figure 6: system dynamic diagram describing competition between two technologies with network effect (left) and with based predatory-prey effect (right).

Figure 6 (left) shows a system dynamic approach to model path dependence of two competing technologies (Sterman, 2000). This model describes a competition between two technologies. Path dependence implies that technologies rapidly lock in to a stable equilibrium when they reach a critical mass. The attractiveness of each product is determined by the effect of compatibility on attractiveness of the product due to the network effect, which can be described by an exponential function<sup>8</sup>:

Effect of compatibility on attractiveness

$$= e^{\text{sensitivity of attractiveness} * (\text{installed base of product} / \text{threshold for compatibility effect})}$$

This shows that the installed base of products should reach a threshold value to have an impact on the attractiveness of the product. In addition, other compatibility elements should be in place for enabling this effect, such as standard cooperation, spectrum availability for sharing, etc. Market share is determined by the attractiveness of product divided by the total attractiveness of all products. This relies in the assumption that these two products have not complementarities.

Figure 4 (right) shows a system dynamics implementation of the Lotka-Volterra equation for a predator-prey competition. Lotka-Volterra equations are described as follows (Pistorius & Utterback, 1996):

$$\frac{dM}{dt} = a_M M - b_M M^2 \pm c_{ME} EM, \quad a_M > 0, b_M > 0, c_{ME} > 0$$

$$\frac{dE}{dt} = a_E E - b_E E^2 \pm c_{EM} ME, \quad a_E > 0, b_E > 0, c_{EM} > 0$$

, where “a” is the growth or positive feedback from the adoption, “b” is the inhibition or saturation coefficient caused by the potential of growth that a technology has and “c” are competition coefficient between two technologies (E and M), in such a way that “c” is positive if the influence is positive, negative if the influence is negative and zero if the influence is neutral. In a predator-prey scenario, prey’s “c” coefficient is positive and predator’s “c” coefficient is negative.

As follows we will analyze end-use centric devices and mobile operator centric devices scenarios through these competition models.

Previous work regarding industry openness and spectrum policy from a system dynamic approach includes the following. Sridhar, Casey and Hämmäinen (2013) explain that a centralized and symmetric allocation of spectrum does not incentive transactions in a secondary market because it does not provide room for improvements in the original allocation, while a market driven decentralized allocation incentive further improvements through a secondary spectrum market. Davies, Howell and Mabin (2008) describe from a system approach how the unbundling favored by regulators to incentives competition can have a negative impact on the incentives for investments due to an increase in the intensity of price competition.

In Figure 7, we show graphically these two models mapped in the graph with two axes used at the beginning of this paper, in which the model related to openness of the industry (a) describes the y-axis) and the model related to spectrum decentralization (b) describes the x-axis).

The previous Bayes analysis (Figure 1 and 2) support the variables used by these models. The Bayesian network of Figure 1 shows that the initial spectrum allocation determines the market concentration (HHI).

<sup>8</sup> The value of a network can be described as “N<sup>2</sup>” by Metcalfe’s law or as “e<sup>N</sup>” by Reed’s law

For our purpose, the initial “disparity in coverage /capacity” of the model of Sridhar et. al. (2013) is herein quantified by the initial spectrum HHI index. Harmonization loop describes a high centralized spectrum policy, while a market based described a decentralized spectrum policy. The Bayesian network of Figure 2 describes the effect of industry openness. While unbundling decreases prices; bundling gives incentives to investments and determine the “price to quality” ratio. This same relation is represented by the model of Davies et. al. (2008) in Figure 4 (b).

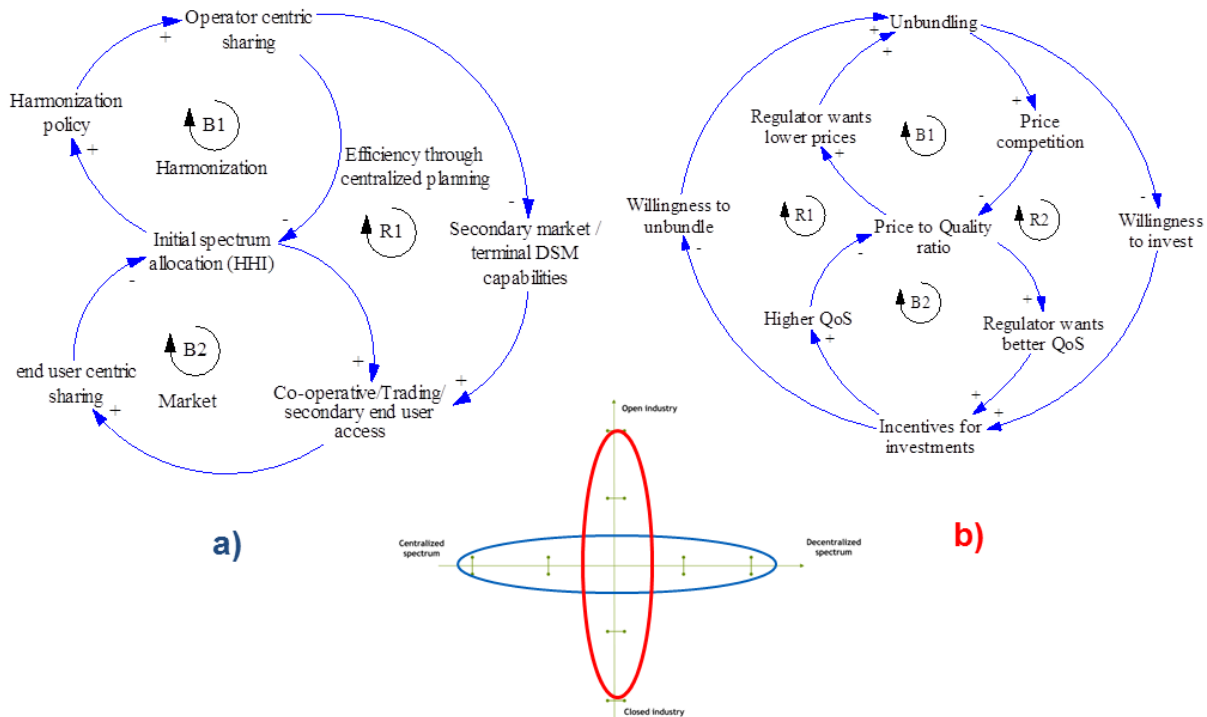


Figure 7: previous work on system dynamics. a) Model of Sridhar et. al. (2013) shows how spectrum market is affected by the spectrum policy (describes the x-axis) b) Model of Davies, Howell & Mabin (2008) shows how unbundling disincentive investments (describes the y-axis)

As follows, we develop a model which describes the introduction of DSM technologies into mobile markets, to analyze different competition scenarios between end-user centric and mobile operator centric devices.

Based on the previous analysis and on the existing literature, we assume that the starting point of spectrum decentralization is the HHI index, which describes the type of spectrum policy practiced by the mobile market. We now consider spectrum property rights regime as a requisite for a decentralized spectrum policy, which enable spectrum availability for sharing. We assume an initial amount of available spectrum for sharing. Through the simulation, the amount of spectrum for sharing will be directly proportional to the market share of end-user centric devices. If devices are mobile operator centric, spectrum sharing will happen only between operators, and thus spectrum policy remains centralized and concentration index high.

In a similar way, we assume that the starting point for openness of the industry is described by the price index and investment per capita. If the industry gets open, price competition drives incentives for cost minimization, and it disincentives the investment for centralized spectrum technologies (Bauer, 2010). Under these circumstances, investing in new decentralized spectrum technologies is more attractive for both incumbent and new industry players. New players can find in DSM technologies an opportunity for lowering their costs of entering the industry e.g., through networks and technologies which do not need a

national coverage. For incumbent players, DSM offers a mean for decreasing their operational costs through a higher cooperation and a more efficient usage of the spectrum. If the industry is closed, incumbents are not willing to invest in new decentralized spectrum technologies and new players do not have incentives to enter in an industry with high entry barriers. In a closed industry scenario, incumbent may favor DSM technologies, based on operator-centric devices, which make a more efficient usage of the spectrum but do not involve the entrant of new players.

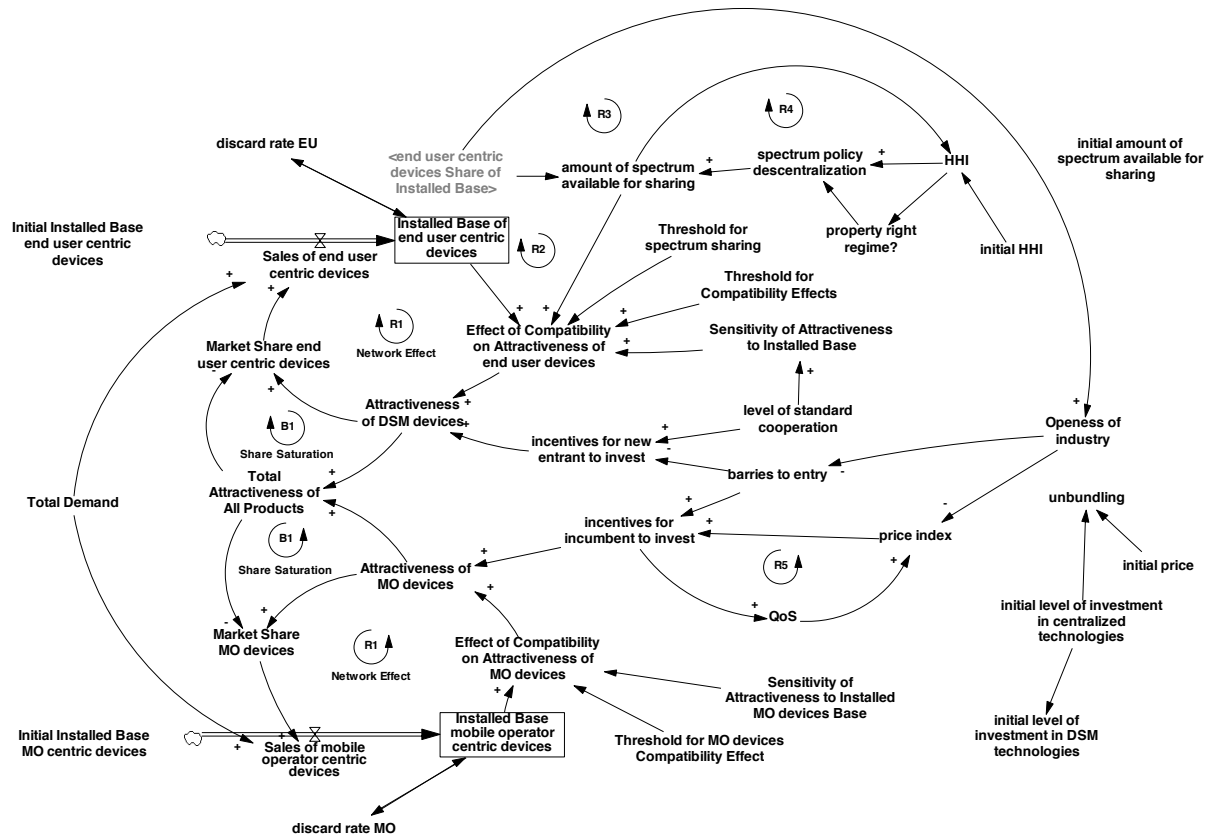


Figure 8: System approach to describe the introduction of DSM technologies considering the network effect

Figure 8 describes the system diagram for DSM introduction with high network externalities. In this diagram, the final output will depend on the initial HHI and openness of the industry parameters. The variables related to spectrum policy, which starts with the HHI index, includes reinforcing loops R4 and R2. On the other side, the variables related to the openness of the industry form a reinforce loop (R5) between price and incentives for investments. In addition, the end-user centric devices share has a positive impact on the openness of the industry, since this type of devices increase handset unbundling (R3). Other loops are those related to the network effect (reinforcing loops R1) and to the saturation effect (balance loops B1).

The level of standard cooperation is also a driver for the introduction of end-user devices. Depending on the type of technology development, the standard may require a modular or integral design. Integral design happens more easily in vertical integrated markets, such as Japan; however, the cooperation between vertically integrated operators could be more demanding. On the other side, if the industry is open (vertically disintegrated), innovation takes the shape of a modular design, within an existing integral architecture. A change in an integral design demand high coordination between vertically separated players

(network manufacturers, terminal manufacturers, operators, etc.). Both, the inability to agree on integral standards or the existence of closed systems have a negative impact for reaching the critical mass (Funk, 2011). Comparing between different scenarios; a mobile operator centric device has a more integral design since its architecture allows the operator to make decisions, while an end-user centric device has a more modular design, since the end user has more freedom to make decisions. In this model, we assume for simplicity that the vertical integration do not affect the level of standard cooperation. Instead, we consider that the level of standard cooperation impacts positively the incentives for investment on new technologies and the sensitivity of attractiveness to installed base.

As a result of the previous loops (R2, R3, R4 and R5), the market can lock into end-user centric devices scenario or to stay in mobile operator centric devices scenario based on commons and exclusive licensing schemes.

Figure 9 shows a predator-prey competition model; our second approach for analyzing the introduction of DSM technologies. This model considers the end user centric devices as predator and mobile operator centric devices as prey (defined in the "competition effect" variable). This means that an end user device can potentially substitute a mobile operator device because it gives the end user an increase in functionality and/or a decrease in price. The growth rate of the technologies is determined by the attractiveness of the technology defined by the level of investments and additionally requires availability of spectrum for sharing. Mansfield (1961) suggests that the rate of technology adoption is directly proportional to the expected profitability and a decreasing function of the size of the investment. From this perspective, a high level of standard cooperation increases the expected profitability and decrease the level of investments, since it allows the exploitation of DSM technologies to all industry players. Therefore, we model the level of saturation for end-user devices as been affected by the standard cooperation and the incentives for investments as been affected positively by standard cooperation. For the mobile operator devices, the capacity remains the same, since it start in saturation level.

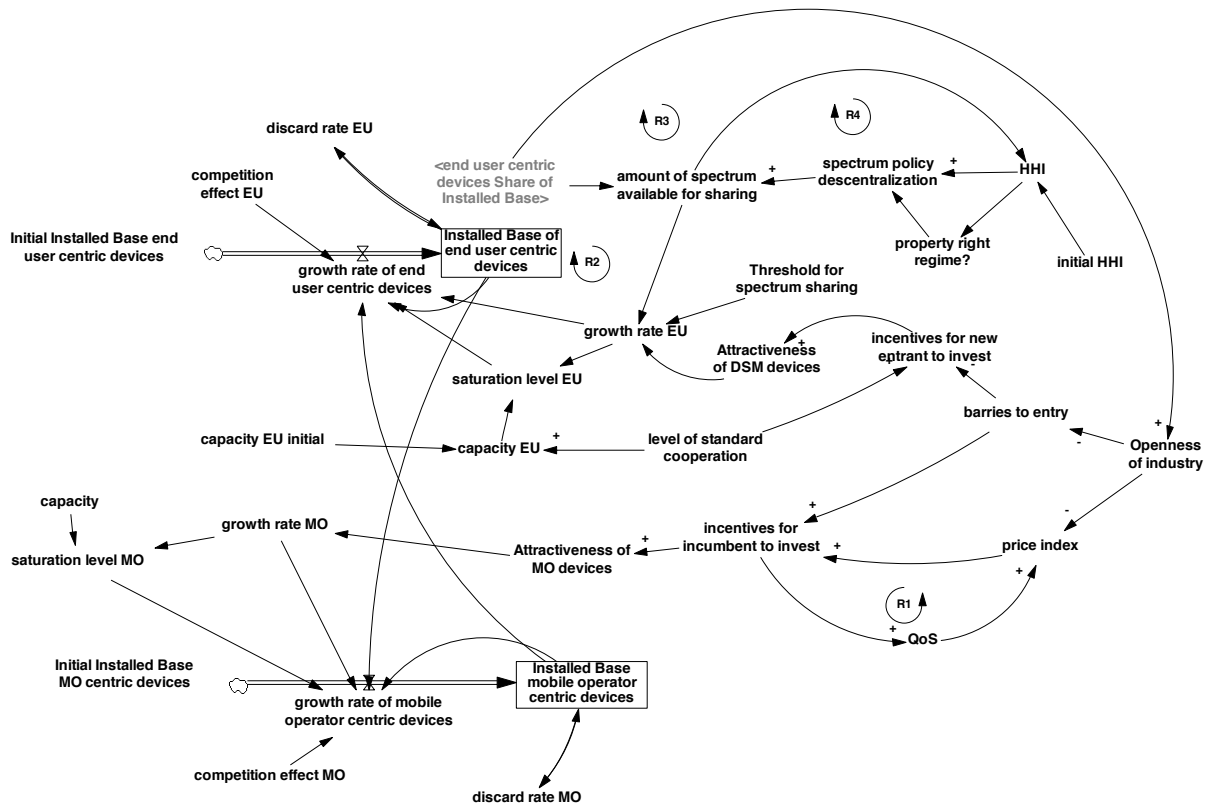


Figure 9: System approach to describe the introduction of DSM technologies based on a predator-prey model

## 7) Results

The simulation results of Figure 10 (a) shows that end-user centric devices are successfully introduced under a low HHI and high industry openness. If these factors do not reach a minimum required level), the industry locks into a centralized management of the spectrum, based on current mobile operator centric devices (b, c, & d).

The initial HHI index together with an initial availability of shared spectrum and a spectrum regime allowing sharing, will facilitates that HHI index get still lower and further spectrum is set as available for sharing. On the other hand, an initial level of unbundling will provide incentives for incumbent and new entrant to invest in different type of technologies. Finally, cooperation in standardization efforts will enable DSM technologies to reach economies of scale and critical mass.

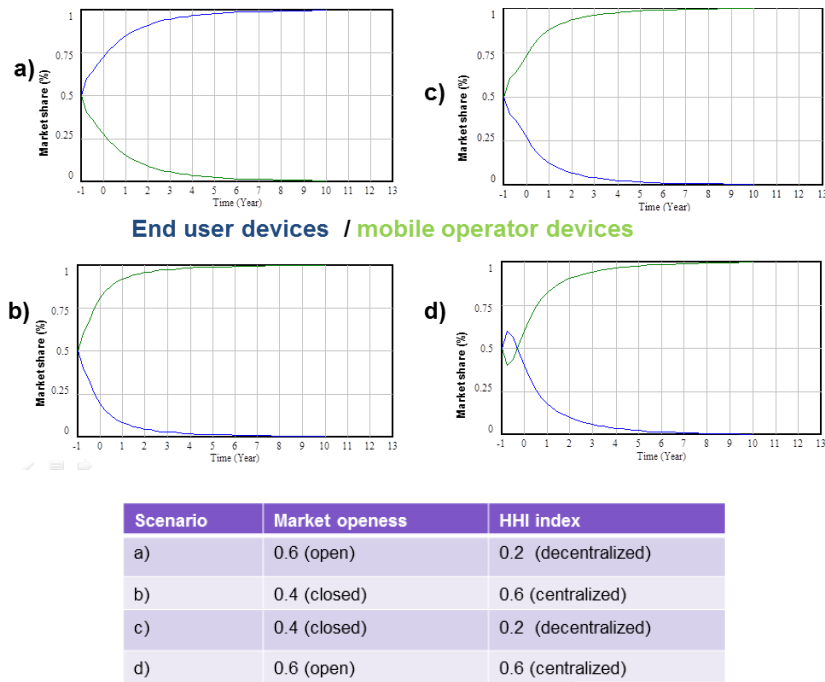
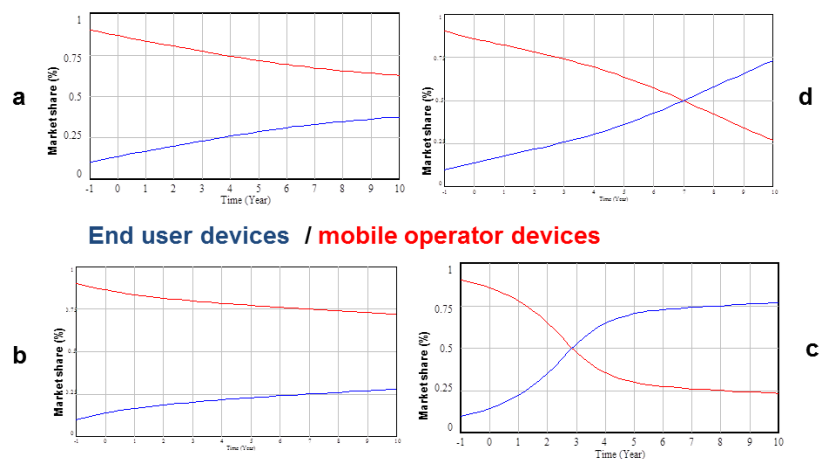


Figure 10: Results for system simulation of a market with strong network effect

Figure 11 shows the results of the simulation using the predator-prey competition model described in Figure 9. It shows that the successful introduction of end-user devices happens slower than with strong network effect, but at the same time, it has more chances to succeed, because of its predator behavior. In addition, the diffusion of end-user centric devices is lightly faster when spectrum is decentralized and industry is open (c against d). When the spectrum is decentralized (d), the introduction of end user devices opens the industry. This resembles the behavior shown by market with multi-SIM mobile phones, such as India (Figure 5), which shows an important price index reduction during the last years. If the spectrum is centralized, mobile operator centric devices continue to dominate the market. Nevertheless, a predator-prey competence model allows certain level of coexistence of both technologies.



	A	B	C	D
HHI	0.2 (centralized)	0.6 (centralized)	0.6 (decentralized)	0.2 (decentralized)
Industry openness	0.9 (open)	0.3 (closed)	0.9 (open)	0.3 (closed)

Figure 11: results for the system simulation of a market with a predator-prey type of competition

## **8) Conclusions**

This paper describes the introduction of DSM technologies by analyzing different mobile market scenarios in a combined approach between Bayes network data analysis and System dynamic modeling. First, this paper classifies different mobile markets and explains their future evolution scenarios, which are defined as: mobile-operator centric and end-user centric evolution scenarios. We describe the evolution of these scenarios, their characteristics and their most critical requirements, by using network effect and predator-prey competition models.

The two different competition models analyzed in this paper show significant different results. Under the presence of high network externalities, end-user centric devices will dominate only under an open industry and decentralized spectrum policy. However, as Figure 3 shows, this is not the current case for most mobile markets. Under a predator-prey model, a decentralized spectrum policy should be enough to drive an end user device scenario.

By modeling the DSM technologies introduction using two different competition approaches, we want to emphasize that the future of these technologies is still open. For instance, the fact that the predator-prey model has more chances to succeed than the network effect model suggest that a strategy for introducing DSM should focus in the substitution of current devices rather than to compete against the older technology through a separate network.

Using the concepts of modular and integral design (Funk, 2011), a modular standard would show a predator-prey behavior, whether an integral standard competes under high network externalities. This means that modular design should help the substitution process while decreasing the network externalities. For instance, WiMAX is an example of an integral technology with high network externalities that failed to succeed, while WLAN and the GSM/UMTS/HSPA/LTE substitution have had a modular competition.

DSM requires still a big effort in standardization and industry cooperation, since some of the changed required by DSM are integral. It is more probable that IETF protocol drive the critical mass, since they can be developed more easily with a modular architecture than 3GPP and ETSI protocols. This finding is also in line with the literature review performed in section 2 (e.g., Kim & Kim, 2007).

An end-user device is more modular as compared with a mobile operator centric device, which has a more integral design. This suggests that DSM introduction will be in reality a combination between these two models. Nevertheless, the dominating scenario in each market will depend on the spectrum decentralization and industry openness.

Finally, this paper gives valuable insights to regulator to understand the current type of policy they are practicing in their countries and the future consequences of their decisions. It also gives a global overview to different stakeholders on how to deal with DSM technologies in a future ICT evolution.

Regulators should analyze if their current type of regulation in terms of industry openness and spectrum decentralization is enough to enable future innovation in a DSM scenario. At the same time, regulators should study the most appropriate mechanism to allow spectrum sharing and trading in their regulations. Table 3 presents a summary of possible type of strategies a stakeholder should perform according to the type of regulation implemented in the market. Incumbent operators should check their current level of cooperation and prepare strategies for spectrum sharing. In this way, they can be ready to take the most



appropriate investment decision when adopting these technologies. Other spectrum holders should think on new business opportunities to actively drive spectrum sharing rather than to have a passive role. New entrants and challenger operators should try to build a competitive advantage from an early adoption of DSM technologies.

**Table 3: Summary of possible strategies of stakeholders considering the type of regulation applied in the market.**

Regulation favors:	Incumbent operator	New entrant or challenger operator	Spectrum holder (other than mobile operator)
End-user centric devices	Take an active role in DSM introduction and be prepare to new innovations	Early adoption of DSM. Focus on innovation	Think on new business models. Become a spectrum or new service provider
Mobile Operator centric devices	Use DSM to decrease costs and increase efficiency	Cooperation with incumbent operators. Offer compatible services.	Share spectrum with operators

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