Analysis of Radio Spectrum Market Evolution Possibilities

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Abstract: A tremendous growth in wireless traffic volumes and a shortage of feasible radio spectrum has led to a situation where the old and rigid spectrum regime is not a viable option for spectrum management and a shift towards a more market driven approach has begun. Great uncertainty still exists over how such a radio spectrum market will come about and what kind of shape it would take. This paper studies some long term macro level evolution possibilities for how this radio spectrum market could emerge and what would be the corresponding value chain configurations. The scenario planning and system dynamics methods are utilized to build four alternative future spectrum market scenarios.

Key words: Spectrum Markets, Spectrum Policy, Flexible Spectrum Usage, Cognitive Radio, Value Networks, Scenario Planning, System Dynamics.

It is commonly agreed that one of the most crucial resources for mobile networks in the future will be the radio frequency spectrum. Thus, the key challenge in designing future mobile networks will be the sharing of the scarce radio spectrum.

Meanwhile the internet is increasingly going wireless and there is a clear trend towards vastly growing volumes of wireless traffic. This growth is fueled mostly by the diffusion of high bandwidth consuming applications such as on-demand video and Peer-to-Peer content distribution, and by a notable increase in the number of wirelessly connected devices. The most extreme estimates predict scenarios where ubiquitous wireless connectivity is given, mobile devices are the primary means for Internet access and 7 trillion wireless devices serve 7 billion people by 2017 (UUSITALO, 2006). Even if these scenarios would realize themselves only partly, it is likely that wireless traffic demand will experience tremendous growth which will in turn result in a massive increase in the demand for radio spectrum. At the same time strong evidence has been presented that parts of the licensed spectrum are severely underutilized (OLAFSSON *et al.*, 2006). These observations have challenged the inflexible planned economy based command-and-control regimes of spectrum management and a shift towards a more efficient and market driven spectrum management has begun. Nevertheless, great uncertainty still exists over how such a radio spectrum market will come about, and what will be the forces shaping the evolution. For example the question of how liberal spectrum regulation will become and how fast this will happen is still to be answered. Spectrum hoarding by the incumbent spectrum owners might also be one force that disturbs the liquidity of the markets (XAVIER & YPSILANTI, 2006; CHAPIN & LEHR, 2007). Some have also speculated whether there even actually is a scarcity of spectrum (GLOVER & NEVOKEE, 2007) and a need for more flexible spectrum management. This paper tries to identify and model these and other trends and uncertainties and identify long term macro level evolution possibilities for how a radio spectrum market could emerge. The scenario planning and system dynamics methods are utilized to build four alternative future spectrum market scenarios.

Methodology

The methodology used is Scenario Planning (SCHOEMAKER, 2000) which is a tool typically used for long range business planning and decision making under uncertainty, but which can also be utilized to analyze macro level development of an industry (SMURA & SORRI, 2009). It follows a ten step process shown in Table 1.

Table 1 - Ten steps of the Scenario Planning methodology.

#	*Step*
1	Define the issues you wish to understand better in terms of time frame, scope, and decision variables.
2	Identify the major stakeholders or actors who would have an interest in these issues, and their current roles, interests, and power positions.
3	Identify and study the main forces that are shaping the future within the scope, covering the social, technological, economic, environmental, and political domains.
4	Identify trends or predetermined elements that will affect the issues of interest from the list of main forces.
5	Identify key uncertainties (forces deemed important whose outcomes are not very predictable) from the list of main forces. Examine how they interrelate.
6	Select the two most important key uncertainties, and cross their outcomes in a matrix. Add suitable outcomes from other key uncertainties, as well as trends and predetermined elements to all scenarios.
7	Assess the internal consistency and plausibility of the initial scenarios, revise.
8	Assess how the key stakeholders might behave in the revised scenarios.
9	See if certain interactions can be formalized in a quantitative model.
10	Reassess the uncertainty ranges of the main variables of interest, and express more quantitatively how each variable looks under different scenarios.

The beginning of the analysis (steps 1 and 2) consists of a scope definition and the identification of the major stakeholders and the value network they form. In steps 3 to 5 the main forces shaping the future within the scope of the study are indentified and analyzed in terms of their importance and uncertainty. The idea is also to study how the uncertainty forces interrelate and in order to make the analysis a bit more thorough, we will complement the scenario planning process by using a method called system dynamics to get a deeper understanding of the interaction between these forces [1].

In steps 6 and 7 four alternative future scenarios are constructed based on two most important uncertainties. After this, in step 8, the stakeholder behavior and reconfiguration of the value network will be analyzed. In the end, steps 9 and 10 are aimed at elaborating the results quantitatively. In this study we will not do the quantitative modeling but leave it for future work.

The work presented here is partly based on Local Area Access provisioning scenarios developed by SMURA & SORRI (2009). Here we will try to expand those from the point of view of spectrum management and especially try to elaborate on the corresponding dynamics. In addition to this, three expert interviews were conducted for background research.

■ Scenario planning analysis

In this chapter we will conduct the analysis according to the Scenario Planning methodology described above. The analysis conducted here is not, by any means, meant to be exhaustive but should serve as a starting point in tackling the complex issue. The research question for our study is defined as follows:

> "How is radio frequency spectrum managed in the future within a time frame extending from 2010 to 2025?"

[1] The combination of scenario planning and system dynamics also resembles a methodology created by the MIT CFP Value Chain Working Group (KLYM & TROSSEN, 2006).

Stakeholders

The stakeholders and actors interested in how the spectrum is shared can be categorized into 5 groups:

- National and international spectrum regulators controlling the spectrum markets;
- Wireless network operators who own and operate the networks, are temporary owners of the spectrum and provide wireless access and services over the spectrum band;
- End-users for whom a service (e.g. mobile voice, internet connectivity or broadcasted television) is delivered to over the spectrum band;
- Device vendors providing terminals through which the services are delivered; and
- Service and content producers and providers.

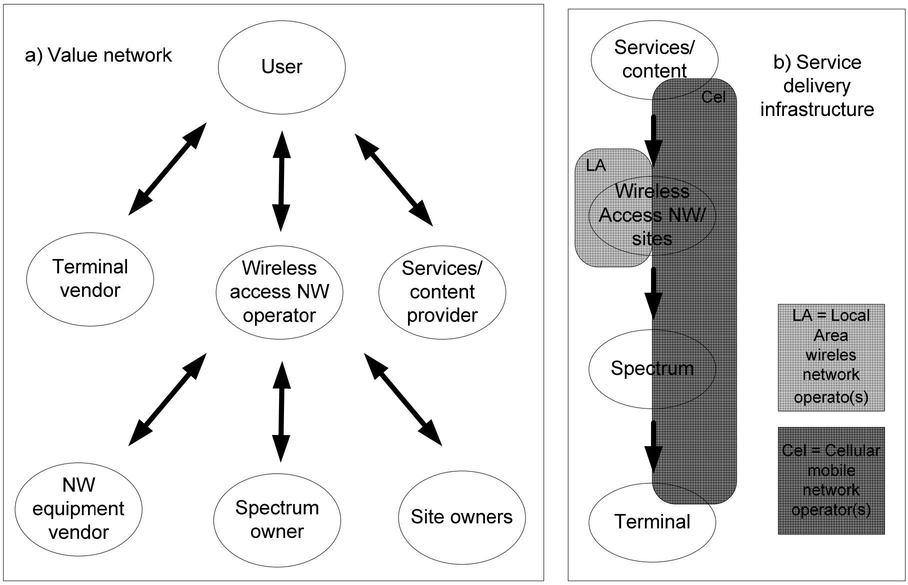
In addition to the regulator, out of these groups the network operator group could be classified as a very interested stakeholder. The network operator group includes incumbent Cellular Mobile Network Operators (MNO) (cellular operators from here on) covering larger regions, Local Area (LA) Wireless Network Operators operating locally, Fixed Network Operators who could be considered as possible entrants to the spectrum markets and also end-users deploying their own private wireless networks [2]. Figure 1 (a-b) presents a simplified description of the value network for providing wireless services and the corresponding service delivery infrastructure [3].

As can be seen, wireless access network provisioning is currently more or less split between Cellular and Local Area operators where the latter mostly consist of end-users deploying a WiFi network over the unlicensed band at their homes in order to share a cable, Digital Subscriber Line (DSL) or other fixed access privately. Roughly stated the same the division could be made between the centrally driven telecom world (mainly driven by 3GPP and 3GPP2) and the internet world (spearheaded by IEEE technologies) emerging from the edges.

[2] In this study we won't discuss broadcasting operators in detail but will put most of the focus on cellular and Local Area wireless network operators.

[3] The service delivery infrastructure can be defined as the architectural components required to deliver and consume the service (KLYM & TROSSEN, 2006).

Figure 1 - Current value network and service delivery infrastructure for mobile services (adapted from SMURA & SORRI, 2009)



Although the service delivery infrastructure does not yet contain a dedicated spectrum broker, in the current setting the regulator could be seen as one (only with very long brokering cycles). Also the network planning and optimization that a cellular operator does to serve a certain spatially distributed traffic demand can be thought of as spectrum brokering within the spectrum band licensed for the operator to operate the cellular network.

In terms of service provisioning one option for value network configuration is that a single user has several contractual agreements e.g. with the device vendor(s) (through a retailer), with the access provider(s) and with service provider(s). This would correspond to a rather horizontal industry structure. Then again in some markets the cellular operators have made a single vertically integrated service consisting of the terminal, access and service thus requiring the customer to only have one contractual agreement.

Main forces affecting the future

Next we will conduct a preliminary analysis of the main forces shaping the future of spectrum management. The analysis is done in four domains: social, regulatory (i.e. political), economic, and technology [4].

Social forces

From the social point of view the core issue is the degree of growth in wireless traffic capacity and spectrum demand. The demand is largely dependent on the growth and diffusion of high bandwidth consuming applications, mainly the different ways to distribute video (CISCO, 2009, e.g. predicts that almost 64 percent of the world's mobile traffic will be video by 2013).

Another factor is the degree of substitution of wired connectivity with wireless. People are gradually getting used to being able to roam around freely while being always connected. Then again, in terms of mobile services most of the value has been in mobile voice and it is an uncertainty whether there will be a similar migration with other applications from fixed to mobile as there was from fixed voice to mobile voice.

The increase in the number of connected devices is potentially another major contributor for wireless traffic demand. Although the traffic volumes that secondary devices (like household appliances) generate might be rather modest, if the number of devices grows substantially they might cumulate to very high volumes of traffic.

Furthermore, flat rate pricing of mobile broadband is becoming increasingly more common and has sparked a hefty increase in data utilization rates (MÖLLERYD *et al.*, 2009). Flat rate seems to be the preferred pricing method for the end-users (MITOMO *et al*., 2007) and the diffusion of the flat rate pricing scheme might become a major driver for the need for more spectrum. Yet another rising trend is the fear of radio emissions. If this trend reinforces itself, it might have severe negative effects to wireless traffic demand.

[4] Many of the forces that are analyzed below were originally identified by SMURA & SORRI (2009).

A crucial question is will the demand for wireless bandwidth and spectrum surpass the supply. Although there is much hype about the tremendous growth in wireless traffic volumes, it might in the end remain reasonable and other technology advancements (e.g. the roll-out of multiple-input and multiple-output (MIMO) technologies) might be able to cater to the demand increase, which in turn might question the need for flexible frequency usage. For example, GLOVER & NEVOKEE (2007) concluded that without spectrum scarcity, the concept of Flexible frequency usage adds little value.

Regulatory (political) forces

There remains a great deal of uncertainty whether market based spectrum regulation will be facilitated in a more harmonized (everybody using the same technologies and spectrum bands) or liberal manner (fragmented technologies and spectrum bands). Hence a core question in terms of spectrum regulation is how liberal it will become.

In the traditional spectrum management regime the use (technology and service), ownership (license holder) and spectrum are tightly integrated. This has been the case for example in broadcasting and also with cellular operators. In order to enable a more market driven way for spectrum management the knit between ownership and spectrum needs to be broken. Roughly stated there are two approaches to accommodate this [5] (OLAFSSON *et al*., 2006):

- Spectrum trading/leasing which enables the temporary or permanent transfer of Spectrum Usage Rights (SUR) from one entity to another; and
- Opportunistic access where devices are allowed to sense and utilize unused spectrum resources in licensed bands without disturbing primary users (either with a commons approach or with the secondary user possibly providing some kind of reimbursement to the spectrum owner) [6].

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[5] The unlicensed bands where everyone has a right to access the spectrum (as long as they follow a certain spectrum etiquette) can also be viewed as flexible usage of the radio frequencies but since it does not come with any ownership of spectrum or any need for reimbursement, we won't consider it as being part of the spectrum markets.

[6] In addition to unbundling ownership from spectrum by allowing secondary leasing or opportunistic access, the regulator can bring more flexibility to spectrum management e.g. by allowing spectrum refarming and the allocation of a spectrum band in a technology and/or service neutral manner (e.g. in many countries in Europe the 900 MHz band, originally allocated for GSM, can now also be utilized by WCDMA).

Secondary leasing of spectrum is gradually getting common. Many upcoming spectrum auctions in Europe will include bands where secondary leasing is permitted and which are in some cases also assigned in a technologically neutral manner. Other countries like Australia, New Zealand, Guatemala, Canada and the USA have already been permitting these for a longer time (XAVIER & YPSILANTI, 2006). In terms of opportunistic access there are also some first steps currently ongoing e.g. with white space [7] usage in the US. In addition to liberalization the regulator can use tools such as Administrative incentive pricing (AIM) to promote the liquidity of spectrum by imposing a cost on spectrum hoarding.

Although the migration towards more liberal spectrum regulation seems certain, it should be done incrementally and with care, since there is a threat of losing control of the spectrum market which might in turn lead to many negative effects such as excessive interference, interworking and roaming difficulties between networks or to the sole deployment of most profitable services, which might in turn jeopardize the provisioning of some critical public services (XAVIER & YPSILANTI, 2006). Since centralized control and harmonization mitigate these negative effects it is uncertain what is the optimal balance between a harmonized and liberalized approach so that the benefits from both could be reaped.

Economic forces

The incumbent operators are naturally favoring the harmonized approach since it decreases risks regarding the diffusion of the technologies they have invested in and guarantees economies of scale effects. The new entrants and advocates of alternative technologies are then again favoring a more liberal approach that allows secondary leasing and technology/service neutrality since it makes it easier for them to penetrate the markets and reduces their risks of entry because there remains also value for exit.

However, even though the regulator would liberalize its regulation, it does not guarantee that the spectrum will be used more efficiently by the incumbents. Since most markets for example in the Cellular Operator business resemble an oligopoly, it might lead to a situation where the few incumbent Significant Market Power (SMP) operators would hoard the spectrum, not secondary lease it and try lock-out entrants, in fear of losing

[7] White spaces refer to frequencies allocated to a broadcasting service but not used locally.

their power in the market. Other reasons for low spectrum leasing activity by the incumbents might be caused by a perception that future increases in value make it worthwhile to hold on to the spectrum, or by a perception that partitioning of the spectrum band would reduce its value. Other reasons might be a fear of transaction and opportunity costs that exceed the potential benefits/revenues gained from spectrum trading/leasing or a fear of cost caused from satisfying regulatory requirements. The regulator can mitigate these by designing well functioning market mechanisms and using tools such as Administrative incentive pricing (XAVIER & YPSILANTI, 2006).

Another reason for the reluctance of cellular operators might be the fact that most of the value is still in rather strongly vertically integrated mobile voice and Short Messaging Services (SMS) where 3GPP based technologies dominate. For these, services, technologies and spectrum bands are strongly bundled and the same combination of spectrum bands and technologies are used worldwide in order to enable roaming and guarantee economies of scale advantages. Nevertheless, the vertical industry structure is currently shifting towards a horizontal form where disruptive technologies - such as flexible frequency usage and VoIP (Voice over IP) and political pressure (regulators actions to promote competition) fuel the decoupling. For example CHAPIN & LEHR (2007) see that flexible frequency usage promotes both the vertical disintegration and horizontal integration of these existing wireless service market silos. The resulting horizontal structure could open doors for new strong players (e.g. large internet service providers) to expand their power in the value chain around the spectrum resource.

If the spectrum markets start to work more efficiently, another uncertainty is how decentralized and local the markets will become. The incumbent Cellular operators could naturally favor a clearly centralized market where the control of the brokering, trading and leasing processes remain with a few. Still, the spectrum is a local resource and one could argue that it can be managed most efficiently in a decentralized manner with local control and market facilitators. If the number of new entrants would grow, it might naturally lead to fragmentation and local spectrum markets. Regardless whether they are centralized or distributed, new entities, such as spectrum databases (or spectrum use registries) and spectrum brokers (or spectrum distributors) are likely to emerge (CHAPIN & LEHR, 2007).

Technology forces

In terms of technology both secondary trading of licensed spectrum and opportunistic access to the licensed spectrum are in early stages of development and the way they will actually realize themselves is heavily dependent on technological advancements.

In its most simple form spectrum trading refers only to the temporary or permanent selling of complete spectrum licenses. In such a case, the brokering cycles would still remain rather long. In order for spectrum trading and leasing to reach its full potential only fragments of the spectrum should be traded within short time-scales. These kinds of complex trading systems could facilitate dynamic pricing of the spectrum and eventually create the basis for a 'real-time' and 'liquid' spectrum market (OLAFSSON *et al*., 2006). Such a real-time brokering system would also need some kind of a subsystem that monitors the utilization of frequency bands in a given location or at least a platform where the interested parties could report their spectrum utilization rates. Such spectrum brokers are also needed to reduce transaction costs resulting from spectrum trading or leasing (CHAPIN & LEHR, 2007). Interference might also become an issue, the more fragmented the trading becomes, and as a result automatic enforcement of Spectrum Usage Rights (SURs) might become very challenging. A central question is also how decentralized the intelligence in wireless networks will become especially in terms of spectrum brokering and what entity will act as the broker.

In opportunistic access to the licensed spectrum devices are able to sense and utilize unused spectrum resources in the licensed band without disturbing the primary users of the spectrum [8]. The feasibility of this approach greatly depends on the development of Cognitive Radio (CR) techniques and the corresponding architectures. Roughly stated there are three alternatives for the technical architecture: a fully autonomous, a collaborative and decentralized, and a centralized approach (OLAFSSON *et al*., 2006).

In the fully autonomous approach each device operates independently and optimizes its own operation in relation to the radio activity. In an extreme case this could be thought of as an everyman's right to access spectrum and

[8] These secondary users could possibly also be subscribers but would pay less to the license band owner for a more 'best effort'-like service.

would thus need a set of etiquette rules. Out of the three this is technically the most challenging architecture since it needs very intelligent and cognitive devices. The less ambitious collaborative and decentralized architecture features Cognitive Radios that form groups where each member senses spectrum availability and distributes this information within the group through a separate control channel. The simplest solution is a centralized architecture where the cognitive radio devices can only access a section of spectrum reserved by the regulator and managed by brokers and databases.

Overall, the maturity of these technologies and the perceived risk of interference must be reduced to an acceptably low level for the market to start working in a healthy manner (CHAPIN & LEHR, 2007). One of the most important technical enablers for flexible spectrum usage is the development of Software Defined Radio (SDR) which greatly enhances devices radio intelligence and re-configurability (KOCH, 2009). So far it has been mostly used for Base Stations and although some are estimating that its diffusion will be fast, there still remains uncertainty on how widely it will penetrate terminals and in general on how fast it will evolve.

Yet another force that might have an effect on the diffusion of flexible spectrum usage is the surplus of existing licensed and unlicensed bands. For example the 5 GHz unlicensed band is still largely unutilized and the digital dividend that is released by the switch in broadcasting technologies from analogue to digital will further cater to the needs. If the demand at the same time would remain reasonable one could question whether there actually is a spectrum shortage. Another open issue is whether the radio interface will actually be the bottleneck or will it (at least partly) be in the wired backhaul of the access network. The diffusion rate of fiber deployments and more advanced DSL technologies enabling higher wired bandwidth might not keep up with the pace of radio development.

Importance, uncertainty and interaction of the forces

Now that we have identified and discussed some of the main forces that could have an effect on how the spectrum markets evolve in the future we will prioritize them in terms of their importance and uncertainty, and study how they interact with each other. The forces discussed in the previous section are first categorized into trends and uncertainties based on their relative uncertainty (i.e. for trends, outcomes can be seen as more predictable) and prioritized based on their importance. The categorized list of forces is depicted in Table 2. The following step in the scenario planning procedure is the examination of how the uncertainties interrelate. As a starting point for this, an estimation of the causal relationships between the uncertainty forces is presented in Table 3 that can be read so that the forces in the rows have an effect on the forces in the columns. A plus sign indicates an effect in the same direction (e.g. as device intelligence and re-configurability (U7) grows, spectrum regulation (U3) can become more liberal). A minus sign indicates an effect in the reverse direction (e.g. as interference problems (U10) increase, spectrum regulation (U3) becomes less liberal). The number of the minus or plus signs indicates the strength of the effect. If the box connecting the forces is empty they have no (major) causal linkage in that direction.

Table 2 - The identified forces categorized into trends and uncertainties

Trends		*Uncertainties*	
T1 (Econ.)	Incumbent operator's fear of new entrants and losing control of the market	U1 (Tech./Econ.)	Locality of spectrum markets
T2 (Pol.)	Threat for regulator of losing control of the spectrum market	U2 (Econ.)	Vertical integration in the industry (services, access tech, frequency)
T3 (Pol.)	Allocation and utilization of unlicensed bands	U3 (Pol.)	Liberalization in spectrum regulation
T4 (Soc./Tech.)	Growth in number of connected devices	U4 (Tech.)	Decentralization of intelligence in wireless networks
T5 (Soc.)	Substitution of wired with wireless	U5 (Soc.)	Demand for additional spectrum
T6 (Soc./Tech.)	Growth of high bandwidth consuming applications	U6 (Econ.)	Possibility and willingness of incumbent spectrum owners to use the spectrum more efficiently
T7 (Econ.)	Incresed number of local operators	U7 (Tech.)	Device intelligence and re-configurability
T8 (Soc.)	Fear of radio emissions	U8 (Econ.)	Vertical integration decoupling forces (disruptive technology, regulator, demand for more flexibility)
T9 (Soc.)	Diffusion of flat rate pricing	U9 (Econ.)	Expansion power of the strongest player in the value chain (e.g. network operator, service provider)
T10 (Tech.)	Bottleneck in backhaul	U10 (Tech.)	Interference issues

Before digging deeper into the explanations between these causal interrelations, we will divert slightly from the Scenario Planning method, and draw a system dynamic model of the interactions of the uncertainties. The model is presented in Figure 2 and it also includes the trend forces. System dynamics is a good method for understanding the underlying interactions of a complex system (STERNMAN, 2000). It can for example be used to identify feedback connections that create reinforcing (positive) or balancing (negative) loops that a system might have. In Figure 2 these loops are highlighted with the circle-like comments starting either with the letter R (reinforcing) or B (balancing). A reinforcing loop consists of a circle of causal relationships whose causal product, i.e. product of the plus and minus signs, is positive (e.g. R_local where the causal relationships between U1 and U4 in both directions are positive). A balancing loop consists of a circle of causal relationships whose causal product is negative (e.g. B_incumb where the two causal relationships from U5 to U6 and from U6 to "Supply for wireless bandwidth" are positive and the relationship from "Supply for wireless bandwidth" to U5 is negative).

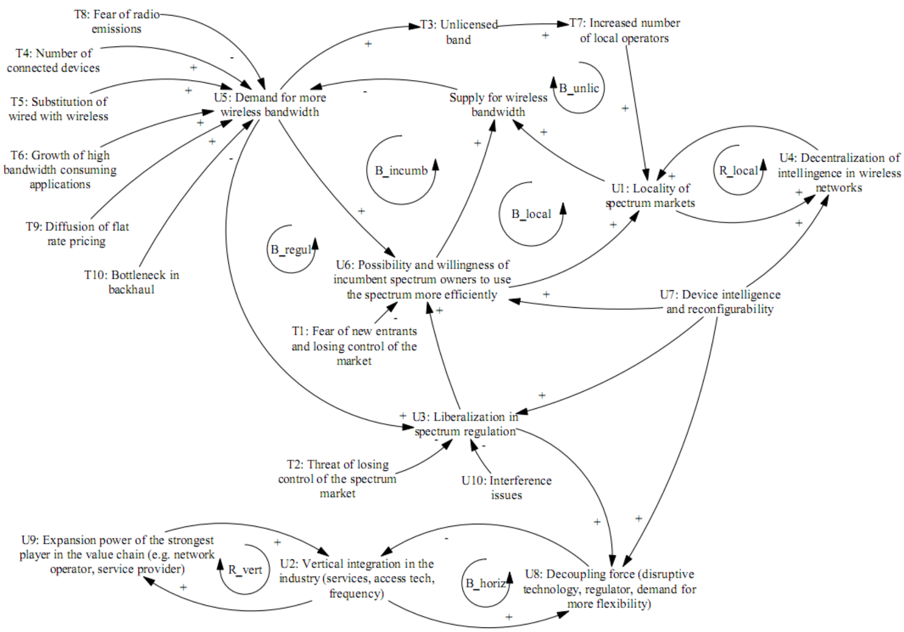
Table 3 - Causal relationships between the uncertainty forces

	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
U1				++						
U2								++	+	
U3						++		+		
U4	++									
U5			++			++				
U6	++									
U7			+++	++		+		++		
U8		- -								
U9		++								
U10			- - -							

Overall when looking at the forces we can see a clear demand-supply kind of a relationship where the increased Demand for more wireless bandwidth (U5) is supplied by more efficient usage of the spectrum. The Demand for more wireless bandwidth (U5) is driven by an increase in the Number of connected devices (T4), growing substitution of wired connectivity with wireless (T5), the growth in video and other high bandwidth consuming applications (T6), and the diffusion of flat rate pricing (T9). Fear of radio emissions (T8) and the degree of backhaul being the bottleneck (T10) have a negative impact on the growth.

This growth in traffic demand is catered by different balancing loops whose relational strengths might vary (i.e. one balancing loop can cater to more of the traffic demand than others). In the B_incumb balancing loop, the increased wireless traffic demand (U5) drives the incumbent cellular cellular operators (who own most of the spectrum) to use the spectrum more efficiently (U6) and thus increase the supply. They might try to do it in a way that prevents new entrants coming into the market. The strength of this loop might be decreased by the operator's fear of new entrants and losing control of the market (T1). In the B_regul balancing loop the growing traffic demand (U5) pressures the regulator to liberalize its regulation policies (U3) which facilitates the spectrum owners to use their spectrum resource more efficiently (U6) (this might be facilitated also with administrative incentive pricing). An increase in the device intelligence and re-configurability (U7) might contribute to the strength of the loop whereas an increase of interference (U10) might hinder the strength of the loop.

Figure 2 - System dynamics model of the trends and uncertainties [(*)]



[(*)] It should be noted that this is just one way of representing the interactions between forces and that alternative interpretations can exist.

Overall the regulator might want to liberalize its policies only gradually due to the threat of losing control of the spectrum market (T2) which could in effect also make the loop weaker. In the B_local balancing loop the increased wireless demand (U5) drives the incumbent operators who own most of the spectrum to lease and sell it forward to new entrants and local area operators who can make small scale market entries and scale up their capacity as needed. This can eventually lead to fragmented local spectrum markets (U1) that are agile and able to cater to the local spectrum demand. This locality is reinforced by the decentralization of intelligence in wireless networks (U4) which is in turn also positively affected by device intelligence and re-configurability (U7). The decentralization of intelligence in wireless networks (U4) might further fuel the locality of spectrum markets (U1) thus forming a reinforcing cycle R_local that supports the decentralization of spectrum markets.

There is also a possibility that a major part of the wireless traffic demand is catered by the B_unlic balancing cycle, where the traffic growth (U5) leads to the allocation of new unlicensed bands which in turn leads to an increased number of local operators (T7) (mostly end users deploying private wireless networks). This installed base could further reinforce the decentralization of spectrum markets (U1). Apart from demand and supply, another interesting domain is the degree of vertical integration in the industry and the forces affecting it. The R_vert reinforcing loop describes how the strongest player(s) in the value chain use their vertically expanded position (U9) to extend, or at least sustain the industry vertically integrated in its favor (U2) which further reinforces its capabilities for expansion. However, as vertical integration grows and some actors become too powerful, balancing forces (U8) usually emerge. These could be for example political pressure for the regulator to increase competition - or liberalize spectrum regulation (U3), or disruptive technologies - like the internet, flexible frequency usage or the growing trend of device intelligence (U7). These emerging decoupling forces establish a balancing loop that drives the industry structure back towards a horizontal form (B_horiz) [9].

Scenario construction

Next we will select the two most important uncertainties, and use them to construct four alternative future scenarios. Based on the relative importance of the uncertainties and the correlation properties (the two uncertainties should be as uncorrelated as possible) we will choose U1 (the locality and decentralization of spectrum markets) and U2 (the degree of vertical integration in the industry) [10].

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[9] The double helix theory has been suggested as one natural explanation of the cycle between a vertically and horizontally structured industry (VCDWG 2005).

[10] By choosing these uncertainties the scenarios also roughly correspond to the scenarios created by SMURA & SORRI (2009) and can be considered as elaborations for those in terms of spectrum market formation.

The constructed scenarios are summarized in Figure 3 that depicts an x-axis ranging from a centrally controlled spectrum market where few entities manage the spectrum to a distributed one where the spectrum resource is controlled and brokered locally and a y-axis (U2) ranging from a highly vertically integrated industry structure where services, access and spectrum bands are bundled to a horizontal industry structure where each level of service delivery is fragmented and competition is high. The scenarios are further elaborated in the following subsections [11].

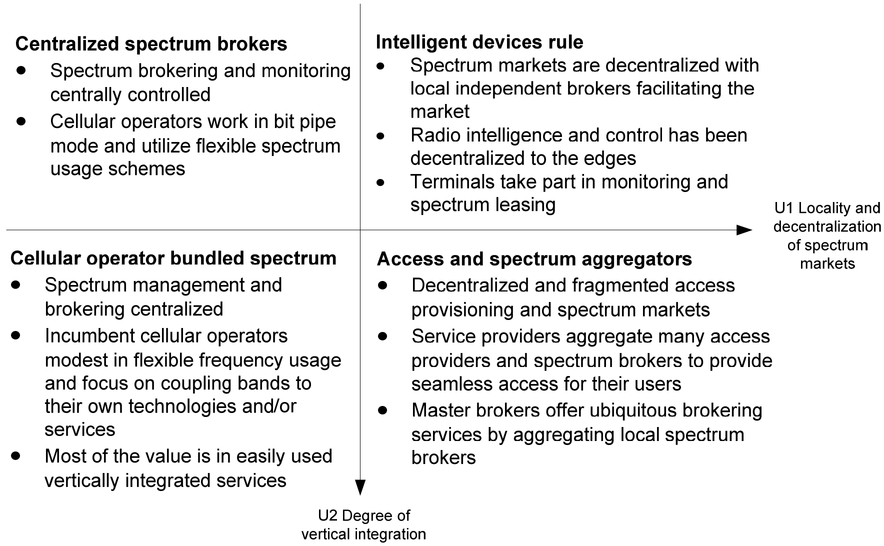
Cellular operator bundled spectrum

In the Bundled spectrum scenario spectrum management and brokering remains centralized and incumbent operators are able to meet a modestly growing demand mostly without flexible frequency usage. The regulator starts to conservatively liberalize spectrum regulation while keeping a close eye on the existence and quality of publicly important services. These opportunities are however leveraged only modestly by the incumbent operators (i.e. limited to spectrum refarming and technology upgrades within the same technology family). The liberalized spectrum regulation is not enough of an incentive for the incumbent operators to start leasing the spectrum. Instead operators hold on to the bands themselves and tie them to their own technologies and/or services. In some cases the Significant Market Power operators might trade or share bands with each other but all in all spectrum markets don't exist in their true sense.

Local Area networks remain a marginal market and are mostly used privately. Overall traffic growth remains rather modest and most of the value is in easily used integrated services. A typical user has only one contractual agreement (with the cellular operator) for everything including access (and spectrum), terminal(s) and service. In terms of the system dynamics model depicted in Figure 2, the B_incub loop is almost the sole source of supply to the weak demand growth, with minor contributions coming also from B_regul, but the other balancing loops remain weak. R_vert loop in clearly stronger than B_horiz.

[11] All in all it should be noted that these are extreme scenarios bounding the future and that the future is likely to be a combination of all of them.

Figure 3 - Four future scenarios for spectrum markets



Centralized spectrum brokers

In this scenario flexible spectrum use becomes common and the spectrum brokering and monitoring system is centrally controlled. The traffic growth is tremendous and operators focus only on being bit pipes and facilitating connectivity. Spectrum regulation liberalization advances rapidly fueled partly by enhancements in device re-configurability. Cellular Operators take advantage of this and are able to provide more bandwidth to the end users without losing too much of the control and market to local operators. The centralized brokers manage a hierarchy of sub brokers that monitor the utilization of the spectrum resource and direct the spectrum resource to where it is most valued. The system is based on one or more dominant technologies and run by Cellular operators with possibly a 3rd party broker working as a facilitator between them. A major part of the spectrum is owned by the cellular operators. Most of the radio intelligence remains in the network and in general the spectrum markets are centrally controlled. A typical user has only one contractual agreement for access and spectrum, but several for services and device(s).

In terms of this scenario, in the system dynamic model in Figure 2, the B_incub loop is very strongly facilitated also by a strong B_regul cycle, that caters to most of the tremendous traffic demand growth. B_unlic and B_local are weak, meaning that the local area operators and the unlicensed band have a smaller role. B_horiz becomes stronger than R_vert reducing incumbent cellular operators to being huge (but possibly rather profitable) bit pipes.

Intelligent devices rule

This scenario assumes that remarkable advancements have been made in every respect of device intelligence but especially in spectrum sensing and other cognitive radio capabilities of devices. In this scenario radio intelligence and control is decentralized to the edges with devices themselves actively taking part in the spectrum leasing process, and collaborating in sensing and monitoring the utilization of the spectrum resource. Ownership of spectrum is also largely fragmented and localized.

The tremendous growth in traffic demand leads to a very liberalized spectrum regulation regime, and to well functioning markets. This in turn leads to incumbent spectrum owners leasing and selling the spectrum to new entrants and local operators and eventually to the decentralization and fragmentation of access provisioning. The agile devices are able to tackle the technology heterogeneity, and access all networks automatically and seamlessly. The regulator has a lighter role and has given the control directly to local operators or to local authorities. Local brokers possibly facilitate the trading and leasing of spectrum for the devices and opportunistic access to the licensed bands is common and works without interference with legacy systems. Access and sharing can even be self-regulated by a society of cognitive devices. Users have many contractual agreements (e.g. separate ones for access, spectrum brokering, services, and devices) but intelligent devices manage these on their behalf.

In this scenario, in the system dynamic model in Figure 2, most of the demand is met with a strong B_local balancing loop. This is facilitated by strong B_regul and B_unlic balancing loops and the reinforcing loop R_local. The device intelligence leads to the decoupling of services from access and spectrum and hence B_horiz loop is stronger than R_vert.

Access and spectrum aggregators

In this scenario the decentralized and fragmented access provisioning and spectrum market is aggregated by service providers who have gained a dominant position in the value chain. The user has only one contractual agreement with a service provider and the service provider has several contractual agreements with access providers. By having roaming agreements with many access providers and also possibly with spectrum brokers a service provider, delivering its service over the spectrum, can provide seamless access for its users. The access providers would be totally transparent to the user and the service provider would control the network selection client in the terminal. Ownership of spectrum is also fragmented and localized with service providers often being an owner or aggregating many spectrum leases into geographically ubiquitous spectrum coverage for their services.

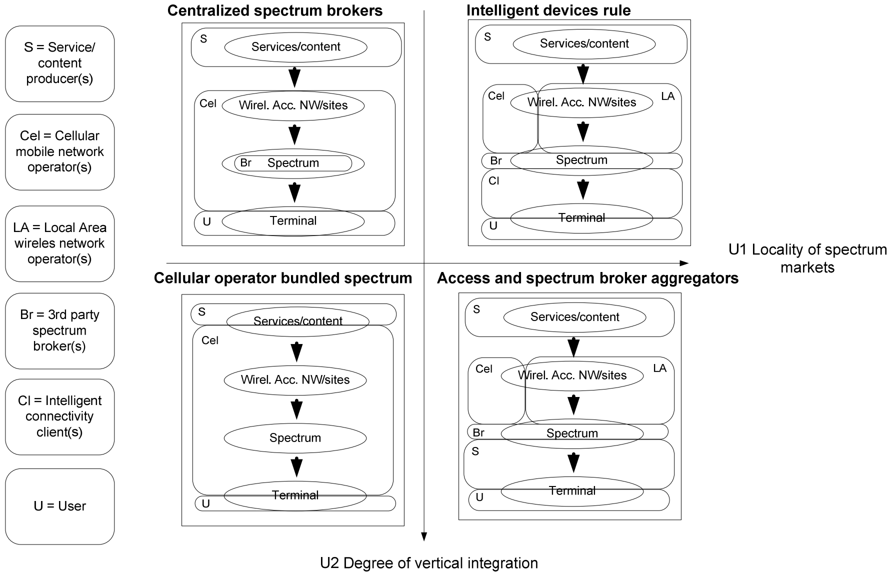
In an extreme case a service provider could aggregate many local brokers and become a master broker offering a ubiquitous brokering service. With such a service spectrum bands could be reserved in advance from wherever the user might roam to. In a way this scenario could be seen as the innovative internet service world coming and taking over the spectrum market. In this scenario, in the system dynamic model in Figure 2, most of the demand is met with a strong B_local balancing loop (facilitated by B_regul, B_unlic and R_local) and R_vert becomes very strong compared to B_horizontal with the powerful service providers re-coupling spectrum and access to their services.

Stakeholder analysis

Last we will shortly describe the position of actors and stakeholders in the above described scenarios. Since the elements around the spectrum resource can be owned and operated by different stakeholders (depending on the scenario) we will illustrate the presence and control of each relevant stakeholder group over the key architectural components required for the service delivery infrastructure. The constellation of stakeholder groups in each of the four scenarios is presented in Figure 4. A stakeholder group is shown in rectangular from where the height illustrates the vertical presence in the service delivery infrastructure and the width roughly depicts the market share of the stakeholder group in that particular part of service delivery [12].

[12] The stakeholder groups can have only partial control of a component and share it with other stakeholder groups.

Figure 4 - Presence of each relevant stakeholder group within the service delivery infrastructure in each of the four scenarios (*)



(*) In addition to the scenarios presented by SMURA & SORRI (2009), the depicted scenarios also slightly resemble the value chains presented by CHAPIN & LEHR (2007).

In the Bundled spectrum scenario the Cellular network operators control the entire service delivery infrastructure around the spectrum resource. This means that the operator partners with white label device vendors and third party service providers and ties the vertically integrated service under its brand. These incumbent Cellular operators have the upper hand in the value network in terms of bargaining with plenty of choices for partners. This also makes it very difficult for new Cellular operator entrants to come in to the market.

In the centralized spectrum brokers scenario the Cellular operators control only the access infrastructure, the spectrum and the related markets. There can also be a centralized 3rd party broker facilitating trade between the operators. In this scenario it is slightly easier for a new Cellular operator to enter the market. Since the Cellular operators are working in bit pipe mode, it leaves room for service providers and terminal vendors to become bigger players in the value chain.

In the intelligent devices rule scenario the role of Cellular network operators becomes limited and most of the connectivity is provided by several Local Access operators. Since spectrum ownership is fragmented and localized this scenario could also call forth many local 3rd party spectrum brokers facilitating the market between spectrum owners and the users. Since the service delivery infrastructure is very fragmented intelligent terminals and connectivity manager clients and their vendors and producers would have an important role.

In the access and spectrum broker aggregators scenario the service providers have a strong hold of the service delivery infrastructure. They would partner with white label device vendors, cellular and local area access operators and spectrum brokers in order to provide one vertically bundled service for the customer and tie the service under their brand. Therefore these service providers would have the upper hand in bargaining power over other actors in the value chain.

Summary and conclusions

In this paper we have studied different long term macro level evolution possibilities for how market driven spectrum management could come about. The scenario planning method and system dynamics were used to build four alternative future scenarios that were based on two key uncertainties: the decentralization and locality of the spectrum markets and the vertical integration in the industry around the spectrum resource.

The four scenarios were: Cellular operator bundled spectrum (vertical industry structure with centralized spectrum markets), Centralized spectrum brokers (horizontal industry structure with centralized spectrum markets), Intelligent devices rule (horizontal industry structure with decentralized spectrum markets), and Access and spectrum aggregators (vertical industry structure with decentralized spectrum markets).

The scenarios represent extreme cases and the future is likely to be a combination of all of them. The presented system dynamic model on the other hand illustrates the dynamics of the identified forces shaping the spectrum market and the possible evolution paths leading to the scenarios. Based on the analysis, changes in forces like the demand for new spectrum or advancements in device intelligence might have an important role in defining the end result. Further work could include more elaborate and quantitative modeling of the identified forces.

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