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Value Network Orchestration of a Cognitive Radio Platform

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Abstract

Mobile communication industry has taken over path of platformisation in terms of service provisioning leading to emergence of different platforms. These service oriented platforms have opened up otherwise closed and vertically integrated mobile industry. However in terms of spectrum licensing and usage market structure is still relatively closed and cognitive radio (CR) technology is expected to be at forefront to solve these issues.

With development of CR technologies new stakeholders are expected to emerge and join existing market players resulting in the development of a multi-sided platform. In this paper we introduce spectrum database driven CR platform as an integral part of CR ecosystem. We visualize its architecture in form of set of layered and interconnected platforms. Higher layer platform for services catering to end-users, lower layer platform for different CR access technologies and a generic CR protocol in between binding these layered platforms.

In order to understand how to orchestrate the value network for different stakeholders to participate in this CR platform, we conducted interviews and identified that stakeholders are in principle willing to move out of their silos and think holistically in terms of CR platform. However political uncertainties and regulatory indecision happens to be major cause of concern hampering stakeholders to make required investments. Also observed that regulators are in position to orchestrate CR market place since their actions influence market, market participants and technology. Thus regulators are required to take steps in direction which promotes harmonization of CR technologies and prevent a fragmented scenario where none of CR solutions attain required critical mass.

1. Introduction

In accordance with the current market structure wireless networks find themselves organized in a closed and vertically integrated fashion. The vertical structure is characterized by proprietary technologies and components that are tightly integrated. A few incumbent Mobile Network Operators (MNOs) and Television Broadcasters (TVBs) take control of the majority of licensed spectrum without any flexible spectrum usage in their operation. Within the unlicensed band of spectrum it is the Wireless Fidelity (Wi-Fi) technology enabling end users for internet connectivity. Considering a typical wireless network scenario, there are a few mobile operators (~3-4) while millions of Wi-Fi access points operating either as 'Private' or 'Public' hotspot. Private hotspots includes those Wi-Fi access points (APs) deployed by the owner of venues such as in homes, offices, cafes, hotels etc. On the other hand, public hotspots are typically deployed by Internet Service Providers (ISPs) or MNOs in locations such as airports and shopping complexes.

Thus as per the nature of wireless networks organized currently, majority of spectrum is found under licensed regime. Moreover it has been argued under different research work that the spectrum is not being utilized efficiently as different instances (Renk et al. (2008), McHenry (2005)) of unutilized and poorly utilized portions of spectrum on spatial and temporal basis have been brought forward. The same has been aided by the regulator's current wireless communication policies which focus on tight control over spectrum users and type of usage rather than adopting a more flexible approach. All this have resulted in underutilized spectrum and slowed down the growth in technology required to combat the exponentially growing wireless traffic and development of innovative services (for the end-users) beyond the ones being used in current scenario.

The ideology of Cognitive Radio (CR) by Mitola & Magurie (1999) has been discussed and researched widely to bring forward a viable solution to this problem. There have been advancements through introduction of different cognitive radio technologies in form of software defined radios, cognitive radio networks, spectrum sensing, database technologies etc. However CR technology is still far off from being deployed on commercial basis. In order for CR technologies to be considered successful in solving the spectrum scarcity issues, it is important that they reach the required critical mass in terms of adoption from different stakeholders of ecosystem. One could use examples from history to find out what were the essential elements required for a technology to become successful and what led to the failure of certain technologies by not reaching the required critical mass. For example technologies such as Global System for Mobile Communication (GSM), Internet and Wi-Fi have been widely popular and successful while e.g. Wireless Application Protocol (WAP) and Digital Video

Broadcasting – Handheld (DVB-H) were strong in terms of technology but failed to create an effective business proposition.

The main reason for success of some technologies while failure of others could be attributed to the fact that successful technologies were able to attain strong ecosystem around them resulting in positive network effects which was not the case with unsuccessful ones. GSM is a prime example where all the market players – Mobile Operators, Network Equipment Vendors, Device Vendors, Regulators and End Users adopted the harmonized technology ensuring that the feedback loop is reinforcing and gets stronger resulting in its worldwide adoption and success. Hence one could argue that the network effects played an important role and we are essentially trying to achieve a pure positive feedback loop for CR technology.

One of the main purposes of this research paper is to identify the factors which might lead to the downfall of CR technology and once those obstacles have been identified, find out the required elements for success of CR technology. On the outset, we also bring forward a hypothesis that a CR platform would be required which all the stakeholders could join and give rise to a new kind of ecosystem. Hence, it would be interesting to identify what are going to be the right conditions for reaching critical mass for this CR platform, such that it has a self-sustaining growth. We also research on finding out a possible architecture suitable for this CR platform such that relevant stakeholders join this platform on the voluntary basis. Additionally, we also identify the most important factors inhibiting market players to make required investments in CR technologies and the steps required to bring the necessary changes to the current scenario.

This paper is organized as follows. Section 2 provides the background theory required to form the basis of the hypothesis of CR platform architecture described later in this paper. Section 3 describes the research methodology used for bringing out the answers to our research questions. Section 4 and 5 presents the findings of our research in terms of the proposed architecture of a CR platform and analysis of the interviews we conducted with the relevant stakeholders of the CR platform. The final section of this paper discusses the findings of our research and draw conclusions on how effectively we were able to meet the objectives of this research work.

2. Background

In this section we provide understanding of those theories which are relevant to design and present the architecture of CR platform and further identify the measures to make this platform a success. In the context of a CR platform we first discuss the two-sided market theory followed by platform theory and finally the critical mass theory.

2.1 Two-sided market theory

In markets with network externality, the relation between different groups happens through transactions. This market may be thought of as a platform enabling transactions. A market is two-sided if the platform's price structure affects the volume of transactions (price increased to one side and reduced to the other maximizes the number of transactions). This happens when players involved in a transaction have different price elasticity, and therefore the total value of the platform is affected by different pricing strategies. The market is one-sided if the volume of transactions depends only on the aggregate price level (buyer and seller sides have same characteristics). For example, the bilateral electricity trading with injection and withdrawal charges is one-sided. Fees are used to cover fixed costs running the transmission system, and they have not impact on transacted volumes.

In a two-sided market the Coase bargaining does not necessarily apply; the optimal allocation of resources may not happen without a high level of cooperation or regulation. In addition, a critical mass may be needed in order to get this market working. If the market is one-sided, the Coase bargaining applies and the market is efficient in itself and regulation or subsidization is not necessary (Rochet and Tirole (2004)).

A market, which behaves as two-sided platform may include: transaction costs between buyer and seller, absent of bilateral setting of prices between seller and buyer, constraints imposed by the platform between users, and membership fixed costs or fees. One of the most classical examples of a two-sided market are credit cards. The payment platform needs to be available at shops so that customers are interested into acquiring a credit card as a payment method. Once the payment platform is widely available, customer will acquire credit cards. The two-sided market theory suggest that sellers are the side with higher price elasticity and therefore the seller should be subsidized, even by giving them for free until a positive feedback loop is generated and the platform creates itself incentives for users of both sides.

This theory can be applied to a Cognitive Radio platform, where one or many sides need to be subsidized or put together into cooperation to achieve a minimum number of transactions, which creates the necessary incentives for all sides to participate.

2.2 Platform theory

Mobile communications is on a clear path of platformization in terms of service provisioning where e.g operating systems, standards, operator portals, etc. can all be seen as a platform. Ballon (2009, 2011) presents a typology of ICT platforms by the level of control over customers and the level of control over assets. As shown in Table 1, a neutral platform does not have control over assets or

customer, while an integrator platform has control over both. Enabler platform has control over assets and the broker platform over customers. Depending on their control on customers and assets, they play a different role as service providers.

Table 1 Classification of platforms according to its typology (Ballon, 2009)

	No control over customers	Control over customers
No Control over assets	Neutral platform	Broker platform
Control over assets	Enabler platform	Integrator platform

Gawer (2009) defines platform as technological building blocks that act as a foundation upon which a group of firms (also called industry ecosystem), develop a set of interrelated products, technologies, and services. Platforms can be seen as an industry platform (Gawer (2009)), which is involved with the industry architecture. Industry platforms are highly dependent on innovation of other firms, so platform leaders should ensure this innovation in complementary products and services. On the other hand, platforms may also be seen as two-sided platforms or more generally as multi-sided platforms (Rochet and Tirole (2004)), which enable transactions between different players. These two views on platforms are complementary in the spectrum market case, where both innovation and the optimization of the level of transaction are both important.

2.3 Critical mass theory

In two-sided markets, where one side has a positive externality on the other side, reaching a critical mass has a high importance. A platform is like an “economic catalyst” (Gawer (2009)), which creates value by bringing together two groups into a platform, which accelerate the “catalytic reaction”. Critical mass is the minimum number of platform participants of one side, which the other side need to get in order to have enough value from participating from the platform. A critical mass must assure enough value that covers the cost and risk of investing in such a platform.

From a system dynamics perspective, a critical mass is reached when the platform generates a positive reinforcing loop, and achieves self-sustaining growth (Casey and Töyli (2012)). System dynamics seeks to understand the behavior of complex systems over time by modeling the feedback structure of a system. System dynamic diagrams consist of causalities where the relationship is positive (or negative) if a change in the causal factor produces a change in the same (or opposite) direction in growth. A closed sequence of causal links represents a causal loop where the causal loop

is “Reinforcing” (or positive) if it has all positive links or even number of negative links. Otherwise, it is a “Balancing” (or negative) loop.

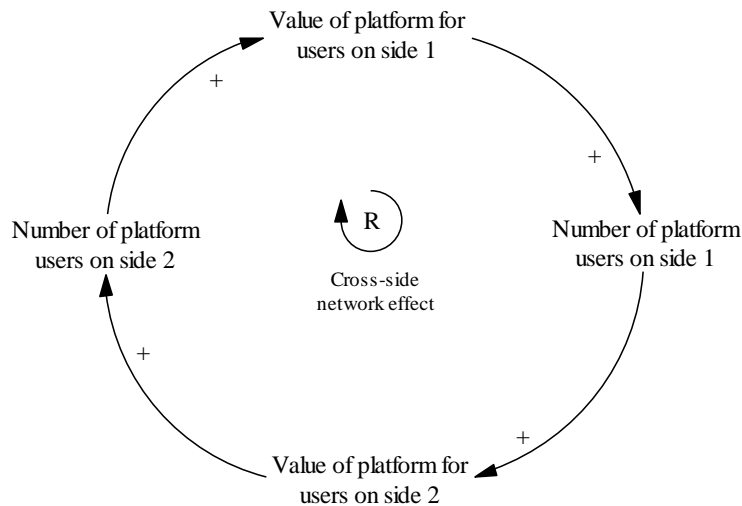


Figure 1 System dynamic view on Cognitive Radio introduction

The Figure 1 shows that when the number of e.g. end-users (Side 1) on one side is increased, it is more attractive for the other side, e.g. industry to increase the service or platform coverage by investing in infrastructure (Side 2) which in turn increases value and attractiveness for the end-users (Side 1). The main challenge of this analysis is to understand which are the factors driving forward the reinforcing feedback loop.

3. Research methodology

This section describes our approach towards the research methodology used for finding out answers to our research questions. Here we first describe the value network configurations which form the basis of our proposed CR platform architecture and following that discuss the interviews we had with relevant stakeholders of the CR platform.

3.1 Value network configuration

We make use of value network configurations to illustrate our hypothesis regarding the architecture of cognitive radio platform. Under this VNC scheme, we adopt the representation of different technical component, their role and corresponding actors undertaking those roles from Casey et al. (2010) as shown in the following Figure 2. Technical components interact through their technical interface and constitute the technology side of CR platform while actors have their

business interface for interacting with other market actors as per two-sided market theory and constitute the business side of platform.

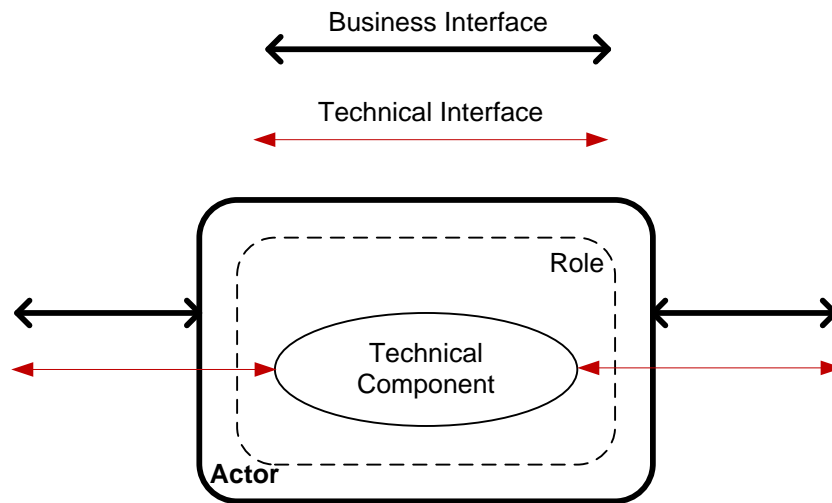


Figure 2 Representation used for showing technical component, their role and corresponding actor taking the role

3.2 Stakeholder interviews

This paper performs expert interviews from stakeholders which may be involved in a future spectrum market, in order to understand the requirements for a successful CR introduction and validating the architecture of our proposed CR platform. The interviewee list included representatives from MNOs, TV broadcasters, spectrum database owners, wireless local area operators, end-user device vendors and national regulators.

First of all, MNOs are currently the main spectrum owners and will be the incumbent in any sort of spectrum market. Local area operators refer to those owning a wireless local area network (such as WLAN network) and using locally the spectrum in an unlicensed or licensed band. The TV broadcasters are in most countries spectrum owners having a stable demand of spectrum and increasing spectrum efficiency, due to the latest digital broadcasting technologies. In addition to these, in many markets new spectrum database companies have emerged, aiming to enable a more intelligent and efficient use of the available spectrum. These spectrum database operators are currently of diverse nature, decentralized and usually their business models are based on an opportunistic usage of the TV white spaces. In addition to this, we interviewed an end-user device and network manufacturer having R&D activities related to Cognitive Radio and Networks. Finally, the regulator perspective is of high interest, because the future success of any Cognitive Radio platform or market depends on the kind of policy developed by the National Regulatory Authority.

The general theme around which the interviews were conducted were as follows -

- Existing and new CR use case/business scenario
- Drivers and challenges for investments in CR technologies
- Validating the architecture of our proposed CR platform
- Fragmentation issues of CR technology and possibility of harmonization
- Spectrum database ownership and regulatory policy implications
- Which side of the platform to be subsidized and by whom?

In addition specific questions were conducted to every stakeholder related to their own participation in a future Cognitive Radio scenario.

4. Conceptual architecture: layered and interconnected platform

Next, we will describe the CR radio platform architecture as a set of layered and interconnected platforms (Stabell & Fjeldstadt1998)). Overall, this relates closely to the layered and modular architecture of the Internet and the Internet Protocol (IP) that is commonly described to follow an hourglass structure, i.e. the IP protocol can interconnect all computers regardless of the link layer technology running below (e.g. Ethernet, WiFi, 3GPP) or application (e.g. HTTP, email, torrent) running above the IP protocol as shown in Figure 3. This also means that the historical evolution of the Internet (Leiner et al. (2009)) and the conditions that enabled the diffusion of TCP/IP, could serve as examples of the conditions required for diffusion of the CR platform.

As it relates to the hourglass model it portrays two important design insights. First is the notion that the network can be carved into conceptual layers. The exact number of layers varies depending on who is drawing the hourglass and why, but roughly put the network can be understood as having three layers. At the bottom is the “physical layer,” the actual wires or airwaves over which data will flow. At the top is the “application layer,” representing the tasks people might want to perform on the network. In the middle is the “protocol layer,” which establishes consistent ways for data to flow so that the sender, the receiver, and anyone necessary in the middle can know the basics of who the data is from and where the data is going (Zittrain (2008)).

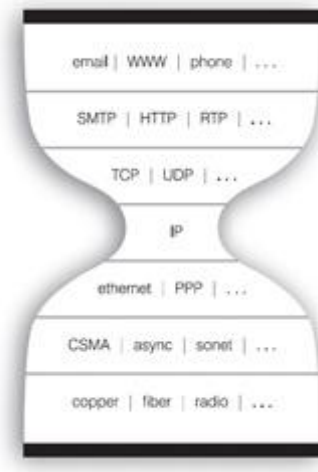


Figure 3 Hourglass architecture of Internet (Zittrain (2008))

The second design insight of the hourglass is represented by its shape. The designers of Internet Protocol did not try to predict what services would be created and what link layer technologies would be used, i.e. what would fill the upper or lower layers of the hourglass. With this loosely coupled technology, anyone could become part of the network by bringing a data-carrying wire or radio wave to the network. One needed only to find someone already on the network willing to share access, and to obtain a unique IP address (Zittrain (2008)).

Using this design approach we introduce the CR platform as a layered and interconnected platform with two layers as depicted in Figure 4. First, a lower layer multi-sided platform comprising of different CR access technologies, MNOs, TV broadcasters, wireless local area network operators, database owners, and spectrum brokers. Second, a higher, service layer platform consisting of the service providers and the end-users representing a scenario similar to a two-sided market. In this higher layer the role of service provider could be taken over by any of the stakeholder who is part of the lower layer multi-sided platform having its own CR access technology. Thus, in principle, end-users can have a number of CR services on offer from MOs, TV broadcasters or local area network operators. It is not mandatory that these market players are incumbents only, i.e. such a CR platform promotes the possibility of new kind of players offering innovative services to enter the market. Thirdly, there exists a generic CR protocol in the middle binding these platforms together. For example the PAWS¹ protocol currently being specified by the (Internet Engineering Task Force) IETF could act as the narrow waist technology interconnecting upper and lower layers.

¹ IETF Protocol to access white space database (PAWS), <http://tools.ietf.org/html/draft-patil-paws-problem-stmt-02>.

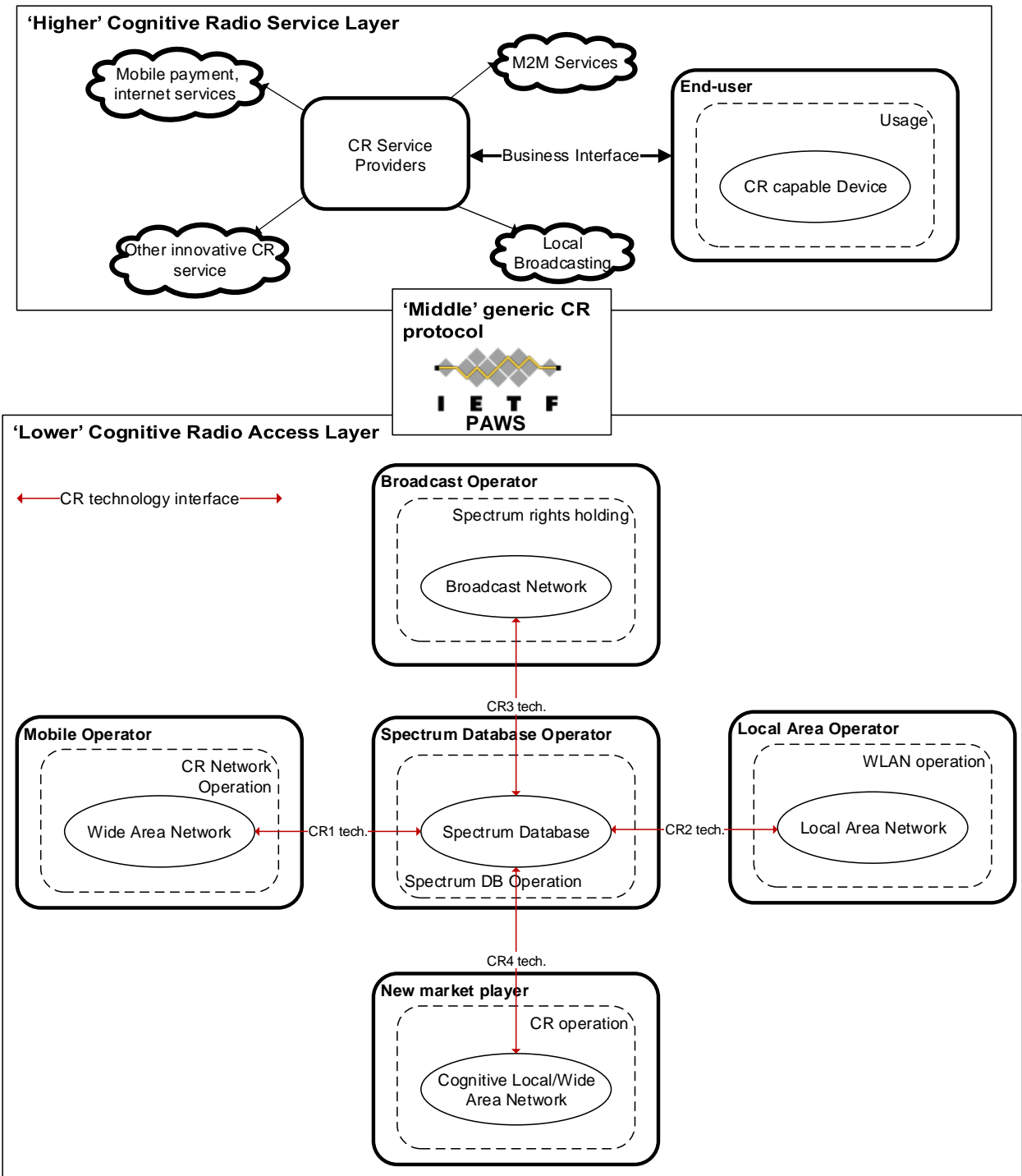


Figure 4 Cognitive radio platform: layered and interconnected architecture

Overall, it could be argued that the success of such a CR platform would depend upon the number of end-users adopting CR capable devices and hence the services being offered on such kind of a platform. Number of users participating in the service layer of the platform would be driven by the number of different services being offered through that platform and additional value these services would bring to the end-users. Examples of such services could be sensor networks, machine-to-

machine communications, intelligent transportation systems, smart grids, mobile payments, building automation, local broadcasting, indoor positioning and hospital and logistics applications.

This in turn would result in a re-enforcing loop i.e. the larger the number of CR services on offer, the more end-users would adopt the CR platform which would in turn drive even more innovation by CR operators and hence bring about new type of services. Subsequently the services on the higher layer of the CR platform could fuel the growth of the lower layer and the diffusion of the CR platform. For example, as it relates to the historical evolution of the Internet, for a long time e-mail was the killer application which, to a large degree, drove diffusion of Internet. A similar killer application is also required to drive the diffusion of the CR platform.

5. Analysis based on stakeholder interviews

We interviewed and presented the above idea of layered and interconnected platform with the relevant stakeholders. By conducting these interviews we wanted to test the hypothesis of the architecture of the platform proposed in the above section. Following that, we made some important observations based on our interviews which we present in this section.

As we interviewed different stakeholders and presented our hypothesis of a CR platform, primary thing coming to forefront was that the success of such a platform would depend upon number of end-users adopting CR capable services and corresponding devices. This coincides with our proposal (as discussed in previous section) that the mass adoption of services being offered in service layer (of our proposed interconnected platform) would fuel in the growth of development of CR access technologies.

Thus, while having our discussions with different stakeholders, use cases in CR scenario were considered to be important for CR technologies to take a leap forward. Next we bring forward different use cases in CR scenario which came up during our discussions.

- **License exempt access to new bands** –The focus is primarily on initial testing of TV white spaces (TVWS) on a license exempt basis (before extending CR usage in other licensed spectrum bands) where LAOs can make use of IEEE 802.11af APs. In order to get the ball rolling in this direction it is required that the chipset vendors start implementing WLAN radio for TVWS.

During our interviews two different perspectives were brought forward regarding this use case. One being that above might not have much of an impact on end-user considering that used Wi-Fi technology is not visible to user at all and thus gaining critical mass from here might not be possible. As a counter-argument, the innovations might be invisible to the end-

users but there are some economical mechanisms having implications through which the mobile devices are able to deploy some technology which would then make operating costs for the MNOs cheaper which at the end of the day bring benefits for the end users.

- **Mobile broadband usage** – The usage in TVWS was primarily talked about where Wireless Internet Service Providers (WISP) providing broadband services specifically in rural areas. This has been demonstrated in all the WS trials so far and seems to be another possible scenario. It represents an extension of fixed line internet (ADSL connections) or the fiber connections especially in the rural areas.
- **Machine to Machine (M2M) services and applications** – The most important stakeholder to launch M2M services are device vendors, both the AP vendors and the end-user devices or communication module vendors. Other involved companies in M2M scenario are the system integrators, which buy these devices from vendors and customize to suit a specific customer's demand. M2M services cover a wide area of services. At follows, we identify two main types:
 - Low bit rate use case; for example electric meter reading. In Finland a large number of electric meter devices have been installed to work with GPRS.
 - High bit rate use case; for example video surveillance. Probability of their success depends on local companies and innovation on their part.

Having discussed the different CR use cases in current market scenario one can argue that they are still narrow in scope and also limited in number. In addition, the only spectrum band considered for spectrum sharing seems to be TVWS. When we pressed upon these issues with different stakeholders, we identified that the lack of investment in different CR technologies is actually creating barriers for new and innovative services to come up in CR space. On analyzing this matter, further we identified a possible root cause of the problem as discussed below.

Stakeholders are in principle willing to move out of their silos and think holistically in terms of a CR platform, which brings new opportunities for all market players. However, the political uncertainties and regulatory indecision is hampering them from making substantial investments in CR technologies. For example, the recently concluded World Radio Congress (WRC) 2012 suggested clearing up the 700 MHz spectrum band to assign it exclusively to MNOs. Going by these indications, MNOs are likely to get 600 MHz band as well and ultimately the entire UHF band. This diminishes the idea of TVWS and CR use cases associated with it. Any concrete decision to be taken over this issue has been postponed till the next WRC. Hence, the political uncertainty on timing over shared and dynamic use of spectrum is causing bottlenecks for required investments and thus slowing down the innovation process in CR technology.

We identify that the regulators are in a suitable position to orchestrate this CR market scenario since they can influence the market, market participants and the technology. However, usually the regulation follows the innovation and not vice versa. The regulators are already acting as spectrum broker, through different licensing mechanisms. They are willing in the future to continue their control in their spectrum usage. If a spectrum market is introduced through a platform, the regulator will have a major role in the spectrum database functionalities, whether they do it themselves or through a 3rd party vendor.

The role of regulators are indispensable and if other stakeholders try to orchestrate the CR market scenario independently, it might result in a fragmented scenario and none of the CR technologies may achieve the critical mass, in absence of cooperation. Many industry players support the idea that harmonization of CR technologies on behalf of regulators is necessary to avoid uncertainty. For example, in the case of GSM the regulators harmonized the technology across Europe which ensured a critical mass within a standard. Also it is important that harmonization should leave space for competition, like GSM did.

Among the other issue that could be deduced from interviews include the difference in outlook over usage of CR access technologies. TV Broadcasters and MNOs resemble each other as they have national frequency licenses and are thus inclined more towards the wide area usage. On the other hand, end-user terminal vendors and LAOs had more of a local area usage outlook. National operators are located in the 3GPP path, while end-users vendors and local operators are more located in the Wi-Fi (IEEE) world. A Cognitive Radio platform has the potentiality of bridging together and hence harmonizing these two different worlds of technologies.

In the end, we observe there is no one specific reason for allowing Cognitive Radio technologies. The main reasons seem to be: scarcity of spectrum, allowing new service innovation through an open frequency management model and investment savings through infrastructure sharing. As we gauged from our interviews with different stakeholders there is no clear evidence that one of these reasons is more important than the other.

6. Discussion and conclusion

As a pre-requisite for this CR platform to succeed, it is required that a critical mass in terms of participation from all the stakeholders is achieved. From our discussions we identified that the stakeholders are in principle willing to move out of their silos and think holistically in terms of a CR platform. However, especially political uncertainties and hence the regulatory indecision over usage of broadcasting and other frequencies seems to be the major concern hampering many of the

stakeholders to make the required investments and is thus slowing down the whole innovation process within CR space. It was also observed that regulators are in a good position to orchestrate this CR market place since their actions influence the market, market participants and technology as well. Thus regulators are required to take steps in a direction which brings in confidence amongst the stakeholders, promotes harmonization of CR technologies and thus prevents a fragmented scenario where none of the CR solutions are able to attain the required critical mass.

Overall, in order to achieve the critical mass it is important that the CR platform offers re-usable components and shared functionalities and in order to achieve this harmonization of CR technologies would be required. One option for harmonization and standardization is the 3GPP driven by mobile operators and their vendors. However, there are concerns that if the CR technology is defined by 3GPP then the MNOs driving the technologies would make the CR platform a more closed one which could in turn slow down the emergence of innovations based on CR technologies. On the other hand the usage of more of open technologies (e.g. standardized by IETF or IEEE) could spur innovations as has been the case with the Internet Protocol.

Furthermore, it is important to consider implications from the point of view of relevant stakeholders. In an open and decentralized scenario, any of the new entrants (such as a LAO) can get hold of spectrum on temporary basis and deploy its CR base station network. This highlights the important role of network equipment and mobile device vendors to manufacture equipment catering this business case scenario where it can take a long of time to develop the needed hardware and corresponding and reach sufficient economies of scale.

As it relates to the different possible use cases the discussion is currently limited to mobile broadband internet access and also machine-to-machine communications to some degree. However, these use cases might be just the tip of the iceberg (e.g. similarly as email was the main use case for the Internet for a long time) and a number of other use cases could emerge which might be difficult to imagine in current the scenario. New and innovative use cases are required to convince customers and improve adoption rate of CR technologies as compared to existing solutions. Furthermore, in order to drive adoption it is required that the technology is cost-efficient and/or provides better services and becomes somehow visible for the end-users.

Finally, the focus so far in terms of CR has been more or less on TV white spaces in the lower UHF and VHF spectrum bands. However, the most recent decisions that have been made regarding the digital dividend seem to favour the exclusive allocation of these digital dividend bands to mobile network operators, and therefore, in the end, white spaces in higher frequencies (e.g. 2.6GHz, 3.5

GHz or satellite bands) might become more attractive for the CR platform. Hence it would be important to start research on how to build CR technologies for these frequencies.

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