ANALYSIS OF DYNAMIC CAPABILITIES IN THE CITIZENS BROADBAND RADIO SERVICE

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ABSTRACT

This paper seeks to identify and analyze the sources of value creation and capture by key stakeholders in the new Citizens Broadband Radio Service (CBRS) shared spectrum access framework introduced by the FCC. More flexible and dynamic use of the 3.5GHz spectrum aims to increase the efficiency of spectrum use in delivering fast growing and converging mobile broadband and media services while paving way to new innovations in technology and business models. In this paper we focus on key stakeholders' capability to deal with combined internal and external resources and capabilities in doing business, referred as Dynamic Capability. Spectrum sharing introducing a rapid change in the technology and business environments requires dynamic capabilities from spectrum offering, spectrum utilization and spectrum management perspectives. We focus on defining key CBRS functional domains and identifying their key antecedents, processes, and outcomes. The DC analysis highlights the key role of the regulator in creating a sharing framework with incentives for all the key stakeholders having different operational and business requirements and enabling scaling ecosystem. Increased system dynamics in spectrum sharing will introduce needs for big data analytics, near real time network management capabilities and low cost 3rd tier general authorized access radios leveraging dominant technology ecosystems. This study provides viewpoints for stakeholders about additional ingredients and actions which may be relevant to further promote spectrum sharing in the form of the CBRS. The concept of dynamic capabilities was found useful to analyze the sources of competitive advantage regarding CBRS spectrum sharing.

1. INTRODUCTION

The rapid growth of mobile and wireless communication systems' users with a large range of diverse services, applications and devices [1] will require significantly more spectrum and wider continuous bandwidth than currently available [2] despite of advances in spectral efficiency and network densification. In order to meet these additional spectrum demands besides identifying more dedicated spectrum, the regulators have globally shown growing interest in novel regulatory approaches related to spectrum allocation, utilization and management. The US President's Council of Advanced Science & Technology (PCAST) report [3] underlined the role of spectrum sharing and dynamic spectrum access to find a balance between the different systems and services with their different spectrum requirements and system dynamics to meet the growing spectrum crisis. Furthermore the FCC sees the opening of the 3.5 GHz Band as "*a new chapter in the history of the administration of one of our nation's most precious resources—the electromagnetic radio spectrum*" [4].

Any spectrum sharing framework to be a feasible and attractive, allowing several radio systems to operate in the same spectrum, calls for early cooperation across government, industry and academia. Collaboration in the technology and innovation domain enables the creation and validation of the technical enablers and new system concepts while ensuring economies of scale and scope in deployment. Furthermore, government and regulation has a two-sided role: key enabler through spectrum harmonization and provision of incentives for early adopters and limiter via competition framework and potentially constraining terms and conditions. The spectrum regulation has enabled multibillion business ecosystems around two distinct spectrum access approaches: mobile broadband businesses via exclusive QoS spectrum usage rights, and at the same time for unlicensed Wi-Fi ecosystem drawing from the public spurring innovations. On the other hand, to date only a subset of the spectrum sharing concepts has reached the regulation domain and furthermore, several spectrum sharing concepts widely researched, standardized and supported by national regulatory authorities (NRA) has not scaled up as expected, TV White Space (TVWS) [5] being the latest example.

Based on this profound cognitive radio and in particular TVWS concept work, two novel licensing based sharing models have recently emerged, the Licensed Shared Access (LSA) [6] from Europe and the 3 tier Citizens Broadband Radio Service (CBRS) governed by the Spectrum Access System (SAS) from the US [4]. For these prominent spectrum sharing concepts currently under regulatory discussion and early stage standardization, and particularly the CBRS, there is not much prior work available in the field of strategic management and business modeling. An initial evaluation of the general spectrum sharing concept from the business modeling point of view can be found in [7] and the LSA focused analysis e.g. from [8] and [9]. This paper extends that work by focusing on more complex and dynamic CBRS sharing concept and analyzing the sources of competitive advantage, value creation and capture using Dynamic Capabilities (DC) approach. Teece et al. [10] introduced the concept of DC to refer to capability to deal with combined internal and external resources and capabilities in doing business in environments of rapid technological change. Teece defines DC as "*the firm`s ability to integrate, build and reconfigure internal and external competences to address rapidly changing environments*" [10]. DC can be described in terms of which actions are taken to adjust a company`s resources into innovate forms of competitive advantage. By analyzing the CBRS concept from the theory of DC perspective, this paper seeks to answer the following research questions:

1) What are DCs required for the processes of spectrum sharing using CBRS?
2) Could this be of help to key stakeholders and regulators for implementing CRRS and SAS?

The rest of the paper is organized as follows. First, the 3 tier CBRS sharing framework and the SAS concept are presented and defined in section 2. Second, the theory of DCs is described including an interpretation of the CBRS concept from the DC perspective. Finally, conclusions are drawn.

2. CITIZENS BROADBAND RADIO SERVICE SPECTRUM SHARING FRAMEWORK

The Presidential Memorandum in 2013 further strengthened the key policy messages of the PCAST report [11] *"...we must make available even more spectrum and create new avenues for wireless innovation. One means of doing so is by allowing and encouraging shared access to spectrum that is currently allocated exclusively for Federal use. Where technically and economically feasible, sharing can and should be used to enhance efficiency among all users and expedite commercial access to additional spectrum bands, subject to adequate interference protection for Federal users, ... we should also seek to eliminate restrictions on commercial carriers' ability to negotiate sharing arrangements with agencies. To further these efforts, while still safeguarding protected incumbent systems that are vital to Federal interests and economic growth, this memorandum directs agencies and offices to take a number of additional actions to accelerate shared access to spectrum."*

After intensive discussion and consultation with the interest groups' the Federal Communications Commission (FCC) released Report and Order and Second Further Notice of Proposed Rulemaking to establish new rules for shared use of the 3550-3700 MHz band in April 2015 [12]. The framework defines a contiguous 150 MHz block at National Telecommunication and Information Administration (NTIA) identified "fast track" band 3550-3700 MHz for mobile broadband (MBB) that the FCC calls Citizens Broadband Radio Service. The 3550-3650 MHz spectrum is currently allocated for use by the US Department of Defense (DoD) ship-borne and ground based radar systems and the Fixed Satellite Service (FSS) receive-only earth stations, while the 3650-3700 MHz spectrum incumbents are the grandfathered commercial wireless broadband service (WBS) users as shown in the Fig.1. The FCC emphasize the role of the CBRS as an "*innovation band*" where spectrum can be assigned to commercial MBB systems like the 3GPP LTE on a shared basis with incumbent systems and promote a diversity of Heterogonous Network (HetNet) technologies, particularly small cells. The technology neutrality of the CBRS will in particular play a role in the opportunistic General Authorized Access (GAA) tier opening up new opportunities for the 3GPP and IEEE WiFi ecosystem co-existence. Rules are optimized for small cell use, but also can accommodate point-to-point and point-to-multipoint, particularly in rural areas. The sharing framework consists of three tiers: Incumbent Access (IA), Priority Access Licenses (PAL) and GAA as shown in the Fig.1.

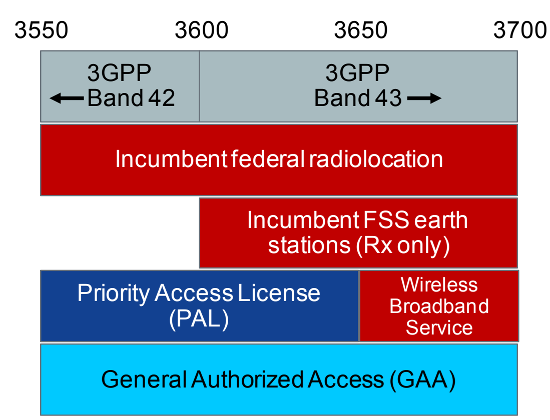

Figure 1. The US 3-tier authorization framework with the FCC's spectrum access models for 3550-3650MHz and 3650-3700MHz spectrum segments

The *PAL* users will obtain FCC licenses to operate up to a total of 70 MHz of the 3550-3650 MHz spectrum segment and are protected from harmful interference from the GAA operations. PAL layer covers critical access users like hospitals, utilities and governmental users and non-critical users e.g. Mobile Network Operators (MNO) and WBS after 5 years sunset on 3650-3700 MHz band operations. PAL users receive short term priority authorization to operate within designated geographic areas such as 3 year 10 MHz unpaired channel in a single census track, awarded with competitive bidding. An applicant may apply for up to two consecutive three-year terms for any given PAL during the first application window. In order to ensure availability of PAL spectrum to at least two licensed users in the highest demand areas, licenses will be permitted to hold no more than four PALs in one census tract at one time. PALs are auctioned to the licensee within their service area but the specific frequencies are assigned by the SAS and they may be changed by the SAS, if necessary. At the end of its term, the PAL will be automatically terminated and may not be renewed. In case the “use it or share” approach will be adopted in full, indicating the opening of PAL spectrum for 3rd tier users when unused, the PAL user should be in charge of determining the “use” status of PALs.

The 3rd *GAA* tier will operate under a *licensed-by-rule* framework throughout the 150 MHz band with minimum of 80 MHz and maximum of 150MHz in each area, subject to incumbent and PAL tier activity. The GAA users have no interference protection from other CBRS users, while it must protect incumbents and PALs. GAA may utilize unused PAL spectrum which requires further investigation on how to realize it in practice. This framework aims to facilitate the rapid deployment of compliant small cell devices while minimizing administrative costs and burdens on the public, licensees, and the FCC. The GAA is planned to provide a low-cost entry point into the CBRS band for a wide array of users and services e.g. personal, small business and campus local hot spots, PAL offload during IA interruption, MBB capacity/offload, backhauling and WBS. GAA users may use only certified, Commission approved CBRS devices (CBSD) and must register with the SAS with information required by the rules e.g., operator ID, device identification and parameters, and geo-location information.

*CBSD*s are fixed or portable base stations or access points, or networks of such stations and can only operate under the authority and management of a centralized the FCC selected SAS which could be multiple as shown in the Fig.2. In case of CBSD is a managed network as in the typical case of MNOs, CBSD includes the *domain proxy* and network management functionality. Proxy could be a pure bidirectional information processing and routing engine or a more intelligent mediation function e.g. combining the small cells of a mall or sports arena to a virtual BTS entity that covers the complete mall or sports arena. The latter option allows flexible self control and interference optimizations in such a network.

End User Devices (EUD) e.g. handsets are not considered as CBSDs. The *SAS* assigns spectrum and determines and enforces maximum power levels dynamically to certified CBSDs at a specific geographic location and time, controls the interference environment and enforces protection criteria and exclusion zones to protect higher priority users as well as takes care of registration, authentication and identification of user information and performs other functions as set forth in the FCC rules. As the IA users have primary spectrum rights at all times and in all areas over PA and GAA, all the CBSDs and EUDs must be capable of two-way communications across the entire 3.5 GHz band and discontinuing operation or changing frequencies at the direction of the SAS to protect the IA.

It is mandatory for all the CBSDs to protect the IA users in the band. Based on nature and critical requirements of the federal incumbent the FCC adopted rules to require *Environmental Sensing Capabilities* (ESCs) to detect incumbent radar activity in coastal areas and near inland military bases in and adjacent to the 3.5 GHz the band. There will be strict rules and corresponding certification for the ESC component in order to ensure confidentiality of the sensitive military incumbent information. When IA activity is detected, the ESC communicates that information to the SAS which if needed could order commercial tier users to vacate a spectrum resource within 60s in frequency, location, or time which when in proximity to federal IA radar presents a risk of harmful interference. Federal IA protection will be introduced in 2 phases: First, a large area of the country outside the static *exclusion zones* will be available after the SAS is the FCC approved and commercially available. At the second phase, exclusion zones will be converted to *protection zones* through the ESC system enabling the rest of the country, including major coastal areas, to become available. An ESC consists of one or more commercially operated networks of sensing device-based or CBSD infrastructure-based sensors that would be used to detect signals from federal radar systems in the vicinity of the exclusion zones. Prospective ESC operators must have their systems approved through the same process as SASs and SAS administrators.

The SAS would obtain the FCC information e.g. about registered or licensed commercial users, exclusion zone areas requiring ESC from the *FCC database*. Functional architecture has option for the *informing incumbent* in-case the federal IA wants to inform the SAS ahead of plans to use the spectrum in some area e.g. related to planed training use of the spectrum.

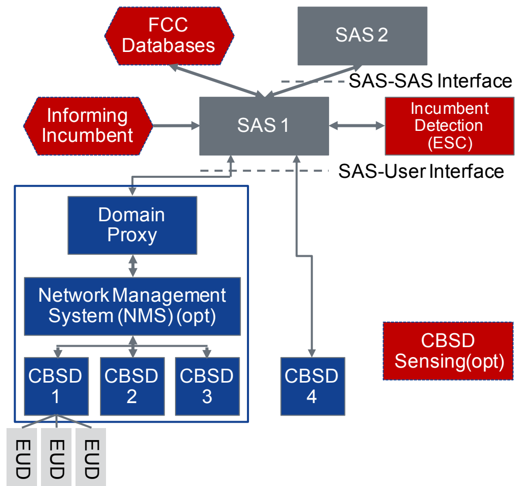

Figure 2. The CBRS functional architecture and key domains [13].

The opportunistic GAA is planned to provide a low-cost entry point into the CBRS band while the PAL system operations have to wait auction process estimated to start after the US 600 MHz incentive auctions targeted for 1H2016. For the meanwhile, the FCC has encouraged multi-stakeholder groups to consider various issues raised by the rules. The Wireless Innovation Forum (WInnForum) Spectrum Sharing Committee [14] with representatives from the government, mobile broadband, wireless, Internet and defense ecosystems serve as a common standards body to support the development and advancement of spectrum sharing technologies with initial focus on 3.5GHz targeted to allow sharing of the CBRS within 2016. Committee has started initial standardization work on functionality and architecture, requirements and interoperability, security, protocols and data models, and testing and verification.

The US Government has initially identified an additional 2 GHz of spectrum below 6GHz owned by federal users for future shared commercial use conditionally, subject to the success of spectrum sharing at 3.5 GHz. This paves the way to make licensed spectrum sharing a third mainstream way of licensing spectrum to commercial users complementing traditional exclusive licensing and unlicensed spectrum access. The FCC has a vision to repeat WiFi success through lowering the entry barrier to QoS spectrum for new entrants and verticals e.g., enterprise, utilities, healthcare, public safety, smart cities, etc. Based on our dynamic capability analysis, we discuss different antecedents, processes and outcomes that potentially motivate incumbents and other stakeholders to see spectrum sharing as an opportunity, and provide views for the regulatory and standardization bodies to be considered when further developing guidelines and policies for spectrum sharing, especially within CBRS and SAS.

3. DYNAMIC CAPABILITIES IN CBRS

3.1. Theory of dynamic capabilities

Strategic management literature is employing DCs to characterize the use of company resources in a rapidly changing environment in order to achieve value creation and capture. The DC approach facilitates the identification of company or industry specific processes that are critical to company evolution [15] in identifying new opportunities and organizing effectively and efficiently to embrace them. In practical use the DC concept can be divided into three domains: the *antecedents* (internal and external factors), the *elements* (contents, knowledge and processes), and the *outcomes* of DCs (linkage to economic performance and competitive advantage) [16].

Resources and capabilities can be conceptualized as hierarchical constructs. At the bottom of the hierarchy are *resources*, zero-order elements [15]. *Operative capabilities,* the first-order elements, skills required for utilizing resources, are higher in the hierarchy [17] followed by the second-order elements, *core capabilities* which are the critical for doing business [18]. In addition to having above discussed capabilities and being able to do something the third order *dynamic capabilities* [19] are needed to be able to create new ways of doing similar things. DCs influence the development and govern the rate of change of operational and core capabilities [19] in a systematic way containing patterned elements and involve learning [20].

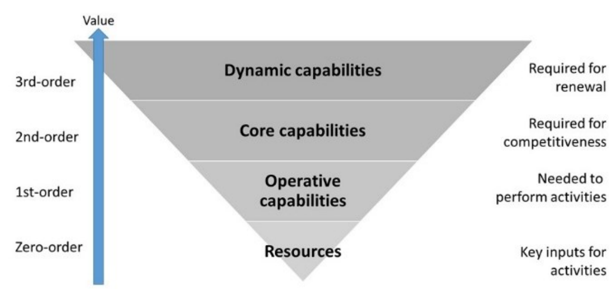

Figure 3. The dynamic capabilities framework.

The DC research scope has recently been widened from a specific company to inter-organizational relationships. For example a company's capability to access and to utilize partners' complementary resources and capabilities as an alternative to developing capabilities themselves or acquiring other organizations' capabilities [21]. In the collaborative DC context, Eriksson [22] pointed out the importance for stakeholders to continuously observe and assess partner activities and the value of the collaborative arrangement. Furthermore, it was found central, that the concurrent activities and outputs of the partners are compatible and can be integrated with those of the focal firm. The DC framework has been applied to mobile communications and spectrum sharing in [23] to derive incentives for incumbent spectrum uses in the static/semi-static LSA concept. In this paper we expand the work by applying DC to the more complex and dynamic CBRS concept.

3.2. CBRS from the dynamic capabilities perspective

Building on the definition of the CBRS, the SAS and the discussion on DCs, we identify five domains in the high level functional architecture where key stakeholders face the need for DCs, considering spectrum provisioning, utilization and its management:

- *Incumbent access* system - the unused excess spectrum required as a starting point that the incumbent has access to;
- *National regulatory authority* – conditions, rules and incentives for sharing between the incumbent and the CBRS users;
- *Spectrum Access System* - database of the information regarding the sharing rules and availability of spectrum to be shared and controller that takes care of the actual control of the sharing by enforcing the sharing rules;
- *CBSD* access networks - the PAL and the GAA access networks that are needed in order to utilize the spectrum. Including optional *domain proxy* and network management system for managed networks;
- *End user devices* - capable of two-way communications across the entire 3.5 GHz band and both the PAL and GAA accesses.

Table 1. below presents those in detail, by looking at the antecedents, processes, and outcomes for key functional architecture domains and their potential stakeholders.

The *incumbent access* system and the excess spectrum are the points of departure for discussing CBRS from DCs perspective. Due to incumbents' mandatory obligations and long life-cycle investments made in their systems, it is natural that they want to continue to use the spectrum they have access to. As an antecedent, incumbents' underutilization of spectrum combined with demand side spectrum crunch has led to a situation where the regulator is pressured to give a "price tag" to spectrum. However, there has to be enough desirable spectrum available to be shared to attract investments. Also, control and appropriability of value related rules over spectrum have to be clear and predictable for the incumbent. In the case of federal DoD incumbent, compatibility with military spectrum management objectives and procedures and long product life-cycles and high relocation costs are important framing elements to consider. Regarding the key processes for CBRS, the incumbent must be capable for identifying and offering the spectrum assets for sharing predictable in the long term. Within the military domain, operational context, like technical user requirements are challenging to access. In inter-domain discussions *military system capabilities models* could be used to address non-material capabilities in addition to traditional platforms and technical systems. Capability system models like US Doctrine, Organization, Training, Material, Leadership, Personnel, Facilities, Interoperability (*DOTMPLFI*) [24] developed to ensure that all functions are considered when military capabilities are being developed and have been applied to analyze how new technologies like cognitive radio contribute changes in the way military conducts its business [25]. The DOTMPLF view capability as a system of interlocking and interdependent components and could be used to access CBRS system from military perspective. As an example, administration of radio systems typically falls into two district domain to consider: procurement and operations. Iterative phased predictable approach to novel spectrum management concepts will ensure continuation of mission critical operations. Based on these antecedents and processes, the outcomes must include retain rights to the spectrum (no re-allocation) with interference protection and possibility save on spectrum fees / create revenue. Additionally incumbent could benefit from relocation and research fund for technology renewal. As a real option the incumbents could also make additional use of the underutilized spectrum in collaboration with civil user. At national inter-agency political level it has become important for military to demonstrate ability and willingness in the spectrum efficiency arena.

The *national regulatory authority* with sharing rules can be seen essential for the CBRS success. As an antecedent for CBRS we identify political willingness to go for sharing with supporting legislation and regulation. Selecting the framework that balances between QoS guarantees and long-term availability and shorter term licenses to enable successor uses to enter the band naturally. On one hand, the increasing demand for mobile services and capacity and related need for additional spectrum, to be used under fair and transparent access rights, serves as a starting point. On the other hand, government direct budgetary requirements and incentives for entrepreneurs and economic growth should support this. It is important to make both PAL and particularly GAA available for early adopters as early as possible for service and business model trials. To speed up go-to-market from technology domain NRA has a role in facilitating inter-domain interference studies, i.e., exclusion zone analysis for initial service. Regarding the key processes, identifying specific bands for sharing through long term planning and the establishment of a sharing arrangement and framework rules and conditions with incentives for both PAL and GAA users plays a crucial role. Enabling process includes improving federal spectrum management and utilization improvement and novel incentive process utilizing, e.g., incentive auctions, administrative pricing or spectrum currency. As an outcome, we identify increased efficiency of spectrum use in particularly through introduction of 3rd GAA tier and more flexibility in spectrum use. Promotion of competition with lower entry barrier to access spectrum empowers entrepreneurs to innovate in vertical markets and intensifies small local operators in urban hot spots and rural. Stable framework to secure investments, shorter transition times, better valuation of shared spectrum and revenue from annual payments can be seen as the outcomes of CBRS.

The *SAS* and SAS administrators form the third area for DCs in CBRS. As a mandatory antecedent we can consider that a standardized functional architecture, with defined interfaces, data models and protocols must exist and the required level of operational and communication security must be maintained. In the overall system SAS plays central role in inter-operability and in controlling the degree of dynamics and complexity. SAS with deep, near real time insight into all CBSDs and CBSD networks, requires core competencies in scalable big data and analytics capabilities and deep knowledge and experience in radio propagation modeling. The key processes in this area founded on employing NRA rules in coordination with other SASs are related to making the spectrum available for sharing. In coordination with incumbent operations through database and incumbent sensing SAS should model aggregated interference generated from CBSDs to the AI, predict and manage interference, detect opportunities and dynamically assign frequency channels. Particular challenge for the SAS function will be the interference originating from distinct networks deployed in neighboring census tracks by different users without coordination. Consequently SAS service could be expanded in the future to cover PAL and GAA co-existence management providing a list of preferred channels based on interference estimations and measurements. SAS should address security towards all involved stakeholders: operational security to protect federal incumbent activity and communication security for authentication, authorization and encryption of SAS-SAS, SAS-Proxy and SAS-CBSD interface. Finally, collected user and context data could be utilized through data monetization business processes according to agreed rules.

At the *CBSD access network* level, exclusive access to QoS spectrum assets over long period has been essential antecedent for a MNO's strategic position in the market. Uncertainty and risks related to regulation in timing, term, licenses and flexibility create exposure and risk for an MNO to proceed with the investment. Furthermore there is an impact on exclusive spectrum licensing model, availability and valuation in the future. Spectrum valuation is complex issue influenced by factors from strategy, technologies, market position and competition, economics and regulatory decisions. As antecedents for CBRS we identify harmonization of technology, utilization of existing technology and spectrum assets, the cellular infrastructure topology, scalable ecosystem and existing market positions of operators. For existing MNOs leveraging the 3GPP LTE evolution as well as for the whole emerging CBRS ecosystem harmonization of radios (,e.g., power and out-of-band-emission limits) and spectrum (alignment with the 3GPP bands) over PAL and GAA is important to achieve scale effect. To enable particularly the GAA tier new low cost BS and AP products are essential combined with access to backhaul bandwidth needed possibly virtualized core network. At the managed network *domain proxy* level we identify as an additional antecedent the near real time network management system for CBSD element management and cross layer and co-existence interference resolution in addition to load balancing between demand and current network load. Current suspension and relocation duration requirement of 60 seconds will mean new technology introduction.

The key processes we see are the configuration and optimization of the CBSDs and CBSD network, according to availability, quality, potential interference level and rules and conditions of the sharing framework guided by the SAS in order to avoid any harmful interference. This requires new CBSD - SAS interface and implementation of protocol work flows. As a point of departure CBSD operator should, optionally in collaboration with SAS administrator, be able to detect spectrum opportunity, evaluate it and make decision on utilization. In the operation phase, initial network planning based on CBRS spectrum availability and existing network assets will be automatically configured and optimized according to band availability and demand, e.g. , through utilizing novel customer experience management (CEM) and self organizing network (SON) features embedded in operations support subsystem (OSS). Additionally CBSD could assist SAS with CBSD infrastructure-based sensors that would be used to detect signals from federal radar systems in the vicinity of the exclusion zones. For CBSD operator entering the local small cell and or vertical business domains calls for dynamic capabilities in business strategy and modeling across domains and verticals.

At this level, the disruptive outcome is the unbundling investment in spectrum, network infrastructure and services flexibility in local spectrum use. More system bandwidth in dense area deployment means less BSs and APs to meet the growing demand. Introduced dynamics and flexibility enable faster access to lower cost extra capacity in dense urban hot spots as well as for rural coverage when and where needed. For established MNOs CBRS enables optimized use across all MNO's spectrum assets with additional PAL with legal certainty and GAA as WiFi offloading replacement with novel LTE technologies like 3GPP as License Assisted Access (LAA) [26]. This would allow operators to benefit from the additional capacity available from the GAA and unlicensed spectrum, particularly in hotspots and corporate environments. With the LAA, the extra spectrum resource, especially on the 3.5 GHz frequency band, can complement licensed band LTE operation. Complementing outcome is opportunity to access spectrum for cable operators, local small cell networks, MVNOs, WISPs… as well as a new access channel for Internet players. The technology neutrality of the CBRS will in particular play a role in the GAA tier. IEEE based technologies will be complemented with novel a standalone version of LTE unlicensed like MuLTEfire proposal [27], which does not require a primary cell anchor in licensed spectrum. It aims on one hand to broaden the LTE ecosystem to entities that may not own licensed spectrum, and on the other hand MNOs benefit from it through offloading and augmenting their mobile networks. New technology introduction should be continuously assessed in relation with added complexity and transaction costs.

Finally at the *end user device* level common antecedent is harmonization and scale of technology and spectrum. Existing technology leveraging on hand ecosystem will reduce strategic risk and speed up market opening and scaling. As an example the EUD emission limits that are compliant with the 3GPP specifications to enable the use of existing 3.5GHz 3GPP Bands 42 & 43 as is in the United States. On the other hand introduction of new full CBRS band will imply need for standardization supported by related R&D. Standardization process of possible new requirements and bands is central in achieving positive outcomes like timely availability of terminals and LTE ecosystem scale up and on the other hand avoid potential negative impacts related to cost, complexity and the GAA device co-existence interference.

Table 1. CBRS in the dynamic capability view

	Antecedents	Processes	Outcomes
Incumbent Access	• underutilized spectrum assets • governmental pressure on defense expenditure • mandatory to continue critical operations • compatibility with military spectrum management objectives and procedures • long product life-cycles and high relocation costs	• identifying and offering desirable spectrum assets for sharing • military system capability model • iteratively phased predictable approach to novel spectrum management concepts • administrative processes in procurement and operations domains	• retain rights to the spectrum (no re-allocation) with interference protection • save on spectrum fees / create revenues • real option to use civil spectrum • demonstrate ability and willingness to contribute • relocation and research fund for technology renewal
National Regulatory Authority	• increasing demand for mobile services and capacity • supporting legislation, regulation and political willingness • government direct budgetary requirements and incentives for entrepreneurs and economic growth • facilitates inter-domain interference studies i.e. exclusion zone analysis for initial service	• identifying specific bands for sharing through long term planning • improving federal spectrum management and utilization • incentive process utilizing e.g. incentive auctions, administrative pricing or spectrum currency • sharing arrangement and framework rules and conditions with incentives for both PAL and GAA users	• further efficiency with GAA • promote competition with lower entry barrier to access spectrum • empowers entrepreneurs in verticals • incentives for local operators • stable framework to secure investments • better valuation of shared spectrum • shorter transition times • revenue from annual payments
Spectrum Access System	• standardized functional architecture, interfaces, data models and protocols • operational and communication security • inter-operability and verification • controlled degree of dynamics and complexity • deep near real time insight into CBRS networks • scalable big data and analytics capabilities • experience of radio propagation modeling	• employing NRA rules in coordination with other SASs • coordination with incumbent operations • incumbent sensing (could be independent sensor network) • predict and manage interference • opportunity detection and dynamic frequency assignment (interference, co-existence) • CBSD authorization and usage monitoring • user data and context monetization	• incumbents protection • Quality of service certainty and guaranteed spectrum for PAL users • optimize spectrum availability for GAA users • monitor and trace the use of spectrum, possible harmful interference, and other phenomena • possibility to use data for license fees and value added services • real option to move towards spectrum aggregator/ broker role
CBSD access networks	• service provider market position • harmonization of technology e.g. power and OOBE limits • utilization of existing tech. assets • certainty and QoS of the shared spectrum asset • near real time network element management system for managed CBSD • network virtualization • managed network interference resolution capabilities • new cheap BS and /AP products	• spectrum opportunity detection, valuation and decision making • network planning based on CBRS spectrum availability and existing network assets • CBSD – SAS protocol work flows • automated network configuration and optimization according band availability and demand (CEM, SON) • assist SAS with sensing capability • SAS assist / domain proxy in co-existence management • business strategy and modeling across domains and verticals	• unbundles investment in spectrum, network infrastructure and services flexibility in local spectrum use • faster access to flexible lower cost extra capacity in hot spots • optimized use of MNO's spectrum • legal certainty only for PAL • opportunity to access spectrum for cable operators, local small cell networks, MVNOs, WISPs… • new access channel for Internet players • concerns over complexity (new elements) and transaction costs
End User Device	• scale of technology • device ecosystem • harmonization of spectrum • full CBRS spectrum coverage	• standardization of possible new requirements and bands	• timely availability of terminals and potential impact on cost and complexity • LTE ecosystem scale up • GAA devices create co-existence interference concerns

4. CONLUSIONS

The paper has presented a framework for analyzing technology and business enablers and sources of competitive advantage for the CBRS functional architecture among key stakeholders, in order to help with capturing the potential benefits and the framing elements of the CBRS concept. By using the dynamic capability approach, we have identified the antecedents, processes, and outcomes of the CBRS in the five basic functional domains for spectrum sharing between users. Building on this analysis, we have provided some guidance for stakeholders about additional ingredients and actions which may be relevant to further promote spectrum sharing in the form of the CRBS. The DC analysis indicated the key role of the regulator in creating a sharing framework with incentives for all the key stakeholders having different operational and business requirements and enabling scaling ecosystem. Particularly, realizing and fine-tuning incumbent spectrum users' incentives could be very helpful in implementing CBRS. By pointing up the DCs involved in taking advantage of the CBRS opportunity, this paper has tried to show how CBRS could be used to complement and improve current mobile broadband services and enable new services and stakeholders particularly in local area and across verticals. This would be, on one hand, valuable to citizens and novel customers in verticals, and, on the other hand, beneficial for incumbents, e.g., by avoiding re-allocations, by providing additional revenues, or by lowering spectrum fees. Furthermore, the incentives triggered by the CBRS may contribute to transitioning from administrative to market-based spectrum management. Increased system dynamics in spectrum sharing introduced needs for big data analytics and near real time network management capabilities. Technology harmonization in spectrum and radios with dominant ecosystems, 3GPP and IEEE, will be essential to ensure economies of scale and fast time to market.

The successful deployment of the CBRS framework will significantly improve the efficiency of the spectrum use, influence the management approach of other spectrum bands and create new business opportunities. This calls for a collaborative effort from the government, industry and academia to build dynamic capabilities needed to incubate and accelerate the development the CBRS and the SAS.

6. ACKNOWLEDGMENT

This work has been done in the Local Area Spectrum Sharing (LASS) and the Cognitive Radio Trial Environment (CORE++) research projects within the 5G programs of Tekes - the Finnish Funding Agency for Technology and Innovation. The authors would like to acknowledge the project consortium members: VTT Technical Research Centre of Finland, University of Oulu, Centria University of Applied Sciences, Turku University of Applied Sciences, Anite, Bittium, PehuTec, Finnish Defense Forces, Finnish Communications Regulatory Authority and Tekes.

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