Wireless Network Virtualization: Opportunities for Spectrum Sharing in the 3.5 GHz Band

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Abstract. In this paper, we evaluate the opportunities that Wireless Network Virtualization (WNV) can bring for spectrum sharing by focusing on the regulatory framework that has been deployed by the Federal Communications Commission (FCC) for the 3.5 GHz band. We pair this innovative regulatory approach with another novel arrangement, Wireless Network Virtualization, and thus assess the resulting opportunities from the perspectives of regulation, technology and economics. To this end, we have established a comprehensive foundation for further exploration and development of virtualized networks that would provide significant opportunities for enabling and enhancing current sharing arrangements.

Keywords: Wireless Network Virtualization · Spectrum sharing

1 Introduction

The complexity of managing electromagnetic spectrum is not purely technical. There are crucial economic and regulatory implications that determine whether an alternative for making more efficient use of this resource would be beneficial or detrimental. Therefore, we perform an analysis that goes beyond the existing technical barriers and extends along three axes: regulation, technology and economics.

In this work, we focus on the 3.5 GHz band and its regulation as well as the innovative technology of Wireless Network Virtualization (WNV) to explore the opportunities and challenges in introducing sharing opportunities. Our study focuses on one particular approach of WNV that is built on resource pooling. Thus, we will study the characteristics of resource pools, the interaction between user types (Incumbents, Priority Access and General Authorized Access users) and how economic considerations drive the definition of networks and the resulting types of competition. We expect that this comprehensive analysis will permit us to solidify the basis for further deployment of an appropriate virtualization environment for spectrum sharing.

This paper is organized as follows: the regulatory framework for the 3.5 GHz band is presented in Sect. 2; Sect. 3 includes a description of WNV and the particular approach that will be considered in this work; Sect. 4 includes a technical

D. Noguet et al. (Eds.): CROWNCOM 2016, LNICST 172, pp. 232–245, 2016.
DOI: 10.1007/978-3-319-40352-6_19

analysis, which presents the two models that could be adapted to the opportunities offered by regulation in the 3.5 GHz band; Sect. 5 analyzes three important aspects associated with Economics, which target at framing our model within this context, and finally, Sects. 7 and 8 present our conclusions and future work, respectively.

2 3.5 GHz Band: Current Status

To date, the 3.5 GHz band in the U.S. has been allocated to federal services (e.g.,DoD radar systems), Fixed Satellite Service (FSS) and, for a finite period, to grandfathered terrestrial wireless operations in the 3650–3700 MHz band [1]. The Federal Communications Commission (FCC) and the National Telecommunications and Information Agency (NTIA) have made a significant effort toward opening this band for shared operations between federal and commercial users. The FCC has referred to this band as an "innovation band," given that the main objective is to enable new spectrum access models that allow the use of modern technologies, thus enabling a move away from legacy spectrum management categories: Federal vs. Non-Federal; Licensed vs. Unlicensed and Carrier vs. Private [1]. The basis of this new spectrum sharing scheme is a three-tiered model for spectrum access, with each tier holding a different level of priority: Incumbent Access, Priority Access and General Authorized Access (GAA). Some important characteristics of these tiers include [2]:

- Incumbent users comprise federal services and some legacy satellite and wireless operations. These users have superior spectrum rights over Priority Access and GAA users at all times and in all areas.
- The Priority Access tier consists of seven channels of 10 MHz each, which can be assigned to Priority Access Licensees. These licensees will have more predictable spectrum access than GAA users. Nevertheless, Priority Access Licenses (PALs)[1] will be granted as long as the demand is greater than the supply in the area of interest. If that is not the case, the entire band will be allocated for GAA use.
- General Authorized Access (GAA) will be granted by rule. In this way, GAA users could potentially access the entire 150 MHz band in areas where PALs have not been issued (or are not in use) and up to 80 MHz where PALs are in use. It is important to note; however, that GAA users will not be protected from interference from other Citizens Broadband Radio Service (CBRS) users.

Through the aforementioned characteristics, it is expected that this three-tiered approach will enable the adaption of spectrum use to market and user demands. Figure 1 illustrates the tentative bandplan, proposed by the FCC, for the 3.5 GHz band.

[1] PALs are defined as an authorization to use a 10 MHz channel in a single census tract for three years. These licenses will be assigned in up to 70 MHz of the 3550–3650 MHz portion of the band [2].

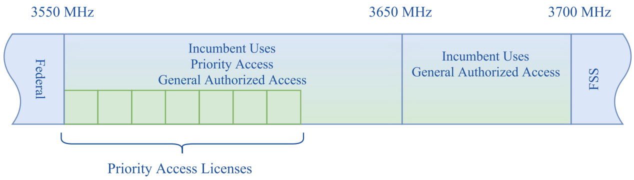

Fig. 1. Tentative bandplan under the 3.5 GHz sharing framework.

Sharing in the 3.5 GHz band will be enabled by a Spectrum Access System (SAS). According to [2], "[t]he SAS serves as an advanced, highly automated frequency coordinator across the band. It protects higher tier users from those beneath and optimizes frequency use to allow maximum capacity and coexistence for both GAA and Priority Access users". In other words, the SAS is an entity that will be in charge of authorizing spectrum access to CBRS users in any frequency and location. Additionally, the SAS is in charge of providing Priority Access Licensees and GAA users with alternative spectrum when they have been displaced by users with higher priorities [3]. In general terms, the SAS should fulfill the *automated frequency assignment* task that will enhance the band management flexibility pursued with this sharing scheme. With the flexible access model developed for this band, the FCC aims at creating a versatile band which will permit to adapt to market as well as technological opportunities [2]. Figure 2 summarizes some important details regarding this three-tiered sharing framework.

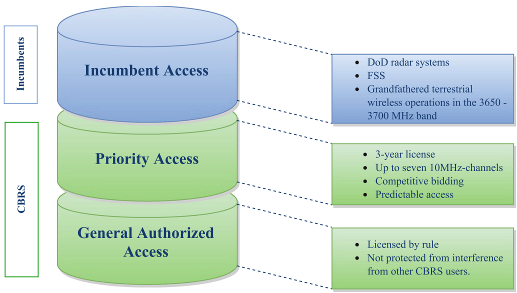

Fig. 2. Three-tier sharing framework

3 Wireless Network Virtualization: The Technology of Choice

From the regulatory approach presented in the previous section, we infer that flexibility for innovation is a key policy objective. Nevertheless, for innovation to be successful we should not only contemplate regulatory flexibility; in fact, we also require that technology allows for adding such flexibility to the network. Along these lines, we find that there is a significant link between Wireless Network Virtualization (WNV) and adding technical flexibility to networks and systems.

Through virtualization, different components of the network are partitioned, combined, sliced and abstracted to create virtual instances of the network. Further, each type of partition, combination or abstraction will yield distinct types of virtual networks giving us the impression that we are working with a *new* network, different from the original [4]. For benefit to be extracted, the virtualization process should be transparent to the users of a virtual network, thus making them oblivious to the underlying virtualization process. As a result, multiple virtual networks operate on one single network, each serving specific purposes and utilizing distinct technologies. Furthermore, co-existing virtual networks may be different from each other [5,6], or as stated in [8], Mobile Network Virtualization "promises multiple personality network elements in terms of virtual ownership by multiple operators. That means multiple networks running virtually (i.e., logically) and concurrently within one physical network equipment or hardware". Notably, this would call for an important degree of isolation embedded in the virtualized systems, which will permit a sound co-existence of virtual entities.

With the adequate application of virtualization technologies, we would be able to devise improved alternatives for the use, sharing and assignment of existing resources [7]. This could provide a degree of flexibility that would aid in maximizing the spectrum access and management options on the operator side. Several alternatives for the application and deployment of WNV have been explored. However, given the characteristics of the new sharing framework for the 3.5 GHz band, we consider virtualization from the perspective of *resource pooling*. This approach requires multiple entities/providers to share their resources in a pool and then make them accessible to alternative users/providers. To elaborate on the resource pooling concept, the authors in [9,10] have compared it to the Cloud (in a computer science context), given that, in principle, it gives us the illusion of an infinite amount of resources, which are available on demand without the need to incur in high upfront commitments and actually permitting users to pay for them on a short-term basis or as needed. Focusing on the idea of *access on demand*, we could expect that the users who have access to the pool will be allowed to choose the resources that are most suitable for a particular service, but which may belong to different incumbents or access tiers.

Centering our attention on spectrum, the objective of pooling this resource is to "enhance spectral efficiency by overlaying a new mobile radio system on an existing one without requiring any changes to the actual licensed system" [11]. Thus, the deployment of spectrum pools would imply a different resource allocation system, where the existing and new hardware can be operated transparently, or in other words, as if there were no other system concurrently present in the same frequency range [11]. In this manner, we can merge the key concepts behind WNV and the creation of resource pools and present them as important alternatives for providing enhanced spectrum access and sharing opportunities [10–13].

4 Technical Design

In this section, we aim at providing a technical overview of the creation of spectrum pools. We will present a *local* and a *global* architecture construct, which will permit us to illustrate some of the benefits that can be derived from virtualization.

Local Approach. In the local approach, we point out potential benefits of the construction and operation of a resource pool within the 3.5 GHz band *only*. From the regulatory approach presented in [2] and as shown in Fig. 1, the assets available for conforming the resource pool are the following:

- 3550–3650 MHz band: 0–70 MHz for PALs and 30–100 MHz for GAA
- 3650–3700 MHz band: 50 MHz for GAA

For the design of this approach we have explored the actual responsibilities of the SAS. Note that, at the basis, the SAS is in charge of the automated allocation of resources (i.e., spectrum access management). Nevertheless, in a virtualized environment, we consider the option of the SAS outsourcing part of its spectrum pool management duties to an external entity known as the *Virtual Network Builder (VNB)*. The VNB is an intermediate entity in charge of aggregating spectrum (and perhaps additional network resources) and offering it to its own customers (i.e., Service Providers). For aggregating spectrum, the VNB should negotiate access with the SAS, and at the same time, it should be aware of the expected demand of the SPs with whom it works. In this context, the SAS would treat the VNBs as large spectrum users or operators. As such, VNBs would auction for PALs from the SAS and compete with other Priority Access and GAA users under the same rules. In a broad sense, this is consistent with the notion of *polycentric governance* described in [24]. This structure is portrayed in Fig. 3.

Given that the VNB should account for the resources to serve the aggregate requirements of its customers, the demand from the VNB should be significantly larger than that of individual entities. When posting bids for PALs, the VNB operations could lead to two important consequences: (1) the VNB can compete with other large stakeholders (e.g., Verizon, AT&T) in terms of the amount that the latter are able to pay for obtaining a license; (2) it is likely that the 'demand greater than supply' constraint for PAL assignment will be met given the aggregate demand that the VNB carries. In this light, this *local* approach provides opportunities for enhancing the sharing arrangements.

As shown in Fig. 3, there is a certain hierarchy among the different entities that belong to this type of network. Indeed, we could associate specific tasks and behaviors to each layer: The SAS would be considered as the regional spectrum access coordinator. It is in charge of the automated process of assigning licenses to the entities in the layer below and, in turn, it is accountable to the regulator (i.e., the FCC) and incumbents in the layer above. The next layer consists of the VNBs or large Network Operators who will negotiate spectrum access directly with the SAS. These will be entities that require larger spectrum assignments

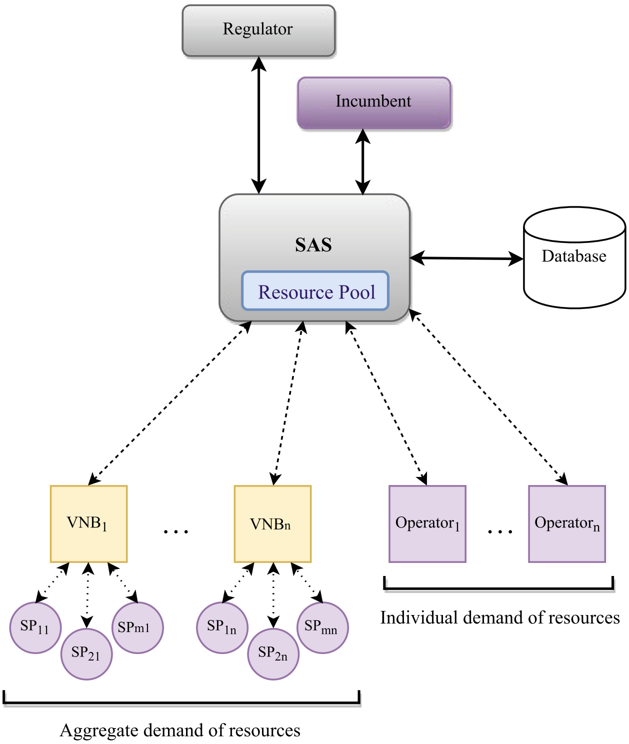

Fig. 3. Virtual network builders as part of the sharing scheme in the 3.5 GHz band

than smaller SPs. The final layer of the hierarchy will be composed of individual SPs who will require spectrum from VNBs or from large Network Operators (as in the case of Mobile Virtual Network Operators (MVNOs)).

We could expect this localized approach to evolve into a virtualized one, especially if we consider pooling resources that belong to multiple providers and we make them available to additional SPs. This type of arrangement can be explained through our global approach, where the virtualization options can be further explored.

Global Approach. A global approach represents a more complex arrangement that targets at adding flexibility to the network and incrementing the opportunities for new entrants. In this scheme, we envision the resources of the 3.5 GHz band as *one* of the multiple inputs to the resource pool. Hence, we would have various frequency bands, licensed and unlicensed, available in the pool, which would represent more possibilities for the VNB to aggregate resources and thus satisfy the service requirements of a larger range of users.

The changes in the architecture under the global approach are shown in Fig. 4. In this case, multiple resource providers (RPs) make their resources available to the pool, which is managed by the VNBs. At the other end, we have various SPs requesting resources from the pool via interactions with the VNBs. Note that the VNBs have also access to the 3.5 GHz band via interactions with the SAS.

The virtualization process in this scenario would be complete when we envision the pool as a set of spectrum and infrastructure resources which can be seamlessly accessed by the RPs and SPs. For this purpose, through WNV, RPs could be utilizing the same infrastructure as the one they are making available in the pool, just on different virtual slices/partitions. If virtualization is properly deployed, we could fully exploit the pooled resources given that we would have the illusion of higher *virtual* availability while preserving the fixed *physical* resources. The VNB would be in charge of aggregating resources upon SPs' demand, which will in turn depend on the specific service that each SP intends to provide. Note that at the basis we would still have physical resources, which are partitioned in different forms. In this way, we would expect the SPs to be compatible and capable of using the virtualized resources offered by the VNB.

These local and global approaches permit the incorporation of WNV, redistribute tasks among different network entities and rely on their interactions to enhance the overall sharing environment. In the section that follows, we look into relevant economic aspects that could help us further evaluate the feasibility of the virtualized approaches.

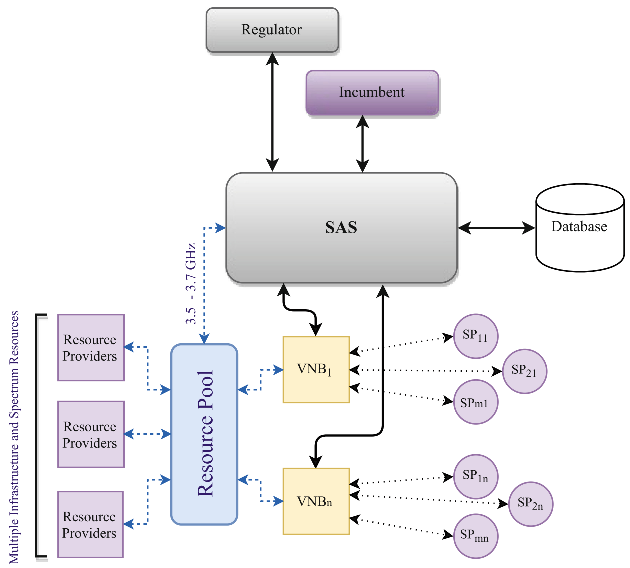

Fig. 4. Generalized approach for sharing and virtualization.

5 Economic Evaluation

5.1 The Innovative Architecture from an Economics Perspective

Innovation has driven significant changes, not only in the technological field, but also on the markets developed to sustain and spread that innovation. In order to place our virtualization ideas within the appropriate context, we would like to point out some significant similarities between our study and the work developed by Hagel and Seeley-Brown in [14].

From the various proposals presented in [14], we find an important similarity between our virtualized approaches and the concept of reverse markets. In such markets, customers can seek the greatest possible value from a broad set of providers which are available at an appropriate time and place. Reverse markets have further led to the design of *process networks*, which are in charge of mobilizing "highly specialized companies across more than one level of an extended business process" [14]. Process networks adopt a *pull* model "where resources are flexibly provided in response to a specific market demand" [14]. When the network needs cannot be easily determined in advance, operators and providers could create platforms permitting them to mobilize their resources readily. This model further suggests a different means to deal with uncertainty given that it can "help people come together and innovate by drawing on a growing array of specialized and distributed resources" [15]. In this light, the ultimate benefit from process networks and pull systems, in terms of uncertainty, would be the possibility of not seeing it as a threat, but as an opportunity to innovate [15].

In this context, we could also associate the characteristics of the VNB with that of a *process orchestrator*, which is an entity in charge of organizing and managing process networks. Some of its duties include determining the eligibility of an entity to participate in the process network; defining the role of each participant in particular process implementation and ensuring that each participant performs as expected and is rewarded accordingly [14]. The orchestrators should focus on expanding the range of participants and creating strong relationships among them. In this way, more specialized skills are accessible, and at the same time, the collaborating parties can build their capabilities faster [15].

To summarize, the local and global models we present in this work adapt to the pull system studied in [14], given that it explores the possibility of generating supply from the aggregation of (specialized) resources belonging to different entities. Additionally, it aims at managing local resource assignment by means of a general orchestrator, which in our models corresponds to the Virtual Network Builder. Since we are dealing with a framework in which different entities (SPs) are providing a service with the aggregation of resources belonging to other operators (RPs), we envision a service-based type of competition. In this way, it is important to shed some light on the nuances, opportunities and challenges of switching from a traditional facility-based competition to service-based competition.

5.2 Facility-Based vs. Service-Based Competition

When we analyze facility (or infrastructure)-based competition and contrast it with service-based competition, we are not facing a "black or white" type of situation. Instead, we can find a wide range of possibilities and arrangements between these two poles. This has important implications in terms of the complexity of the strategies adopted by incumbents and entrants and the regulatory schemes that are optimal.

At the core of these competition decisions, we have a set of trade-offs that incumbents and entrants should take into account. Indeed, each user will decide to enter in either arrangement depending on the level of profitability that it represents. For instance, incumbents should evaluate the benefit from investing in their own infrastructure and share it with new entrants versus the possible threat of competing with new market entrants who possess their own market infrastructure. New entrants, on the other hand, should determine how limited their competitiveness will be in the market if they are subject to the lease arrangements provided by the incumbents, and at the same time, they should contrast those limitations with the investment required for deploying their own infrastructure (i.e., opportunity cost of technology adoption) [16,17].

Referring to a traditional view of networks, we find that it widely favors facility-based competition and sees service-based competition as the stepping stone for the rise of the first. Nevertheless, if we adopt the process networks perspective presented in Subsect. 5.1, we could envision models and systems that successfully operate under service-based competition. Furthermore, when adapting our virtualization considerations, a wider array of resource usage models can be considered, which not only represents additional service opportunities for the new entrants, but also decreases the threat that these users can pose to the incumbents, e.g., threat caused by new entrants providing the same service as the incumbent. Moreover, the aggregation and assignment activities of the VNB could make the negotiation process easier for entrants and incumbents, thus reducing the associated costs. In this way, we would obtain positive conditions for a successful switch toward service-based competition.

5.3 Value Chains vs. Value Networks

According to [12], "[t]he value chain includes all the activities that exist as a direct result of usage of the cellular network. The purpose of creating the chain is to understand where the costs are incurred and the revenue is generated". Generally, a value chain is associated with a particular network operator or incumbent, and it will help to determine the activities that will be more profitable. Due to the significant changes in spectrum sharing arrangements, technology use and service availability, we can expect that the traditional value chain will shift to new perspectives in which, not only an incumbent's view on how to derive value from its resources and make profits is considered; instead, we might be interested in a new approach which encompasses the interactions of multiple users for generating valued services.

We have already evidenced examples that portray significant changes in the structure of value chains, such as the appearance of MVNOs, the evolution of Wi-Fi which has turned its hotspots into important complements of regular mobile networks, and also the creation of over-the-top services. From these examples, one can notice that different parts of the value chain that generate revenue, can be actually controlled by entities different from those that have deployed and control the parts associated with the highest costs [12]. In this way, as value chains continue to evolve, it is possible to observe how various value chains become intertwined for the creation of more complex networks where different entities are simultaneously involved in more than one value chain. We can refer to these as *value networks*.

A value network presents multiple entry and exit points, which increase the complexity of operations for all the members involved [20]. Additionally, it is expected that this network will be formed by "different actors drawn form a range of industries that collectively provide goods and services to the end users" [20]. For this purpose, these industries should show a higher level of specialization in particular activities, instead of managing the overall production of services. Furthermore, the companies involved are expected to dynamically evolve and perhaps specialize and gain expertise in additional areas. Hence, for the final service provision, relationships among multiple, specialized companies should be established [20].

This new notion of specialization and interaction among entities, calls for the modification of the boundaries of a company, which is evidently accompanied by a corresponding trade-off: value of specialization versus the transaction costs associated with external suppliers [20]. In this light, for setting their boundaries,

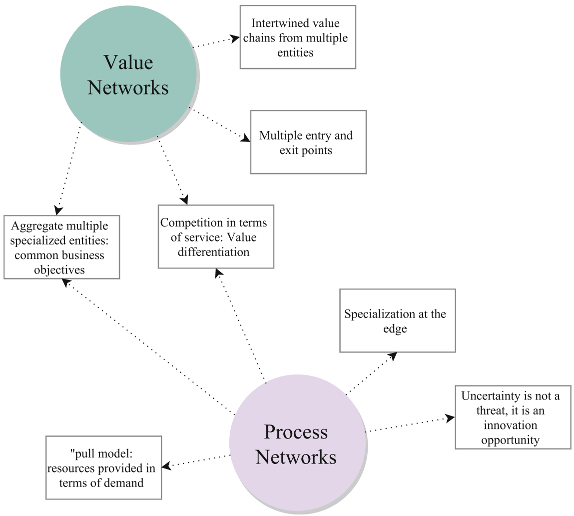

Fig. 5. Similarities between process and value networks.

firms should consider a balance between facing low transaction costs from internal production of services, thus lower agency costs and the economies of scale derived from obtaining resources from external entities [20].

Ultimately, the interaction of multiple users proposed by the value network approach permits us to study a firm's relationship with other network members and thus understand where value lies in the network and how it is created by multiple parties; how the activities of a firm will affect the network and how other members are likely to respond [21].

From the concepts presented in this section, we can find the relationship between value networks and process networks, which are illustrated in Fig. 5. Both mechanisms envision the aggregation of specialized entities to provide valued services, targeting at the deployment of service-driven networks and the accompanying type of competition.

6 Putting Things Together

Analyzing the network presented in Fig. 4, as a whole, we can point out important details that map to the concepts presented throughout this paper.

The entities in this network may have different degrees of specialization in multiple areas. In turn, these entities share their resources with others, thus promoting the development and provision of additional, perhaps more specialized services. This creates intertwined value chains as there is greater value extracted from a set of resources initially owned and used by a reduced group of incumbents or RPs. Additionally, this translates in a wider array of services provided throughout the network, which defines it as a service-based competition environment.

From the perspective of the RPs, there are increased opportunities for analyzing whether participation in the pool results in a profitable arrangement. This presents them with options to continue to participate, increase their participation or exit the network. The SPs at the other end of the network will generate a dynamic demand, dependent on the type of service that lies at the core of their business model. This represents less restrictions in terms of resource access and thus definition of the service to provide.

In a traditional system-based competition model, each SP would need to negotiate with every RP from which it requires resources. This is not a practical solution in terms of transaction costs, and possible restrictions in the establishment of leasing agreements with RPs. In the network we study, both RPs and SPs will negotiate resource access with a single entity: the VNB. In fact, the VNB will aggregate the required type and amount of resources based on the demand of the SPs, which is expected to be service-specific and dynamic. At the same time, the VNB should be in charge of providing the appropriate compensation to the RPs and/or negotiating with the SAS depending on the type of resources accessed.

Note that the flexible management of the resources belonging to the pool responds to the utilization of an enabling technology such as wireless network virtualization. In this way, the co-existence of multiple RPs and SPs would be ensured. It is evident that there is a greater degree of flexibility stemming from this network when compared with traditional system-based or facility-based competition arrangements. In the case of the latter, we can expect higher transaction costs associated with negotiations, given that specific leasing agreements should be developed among particular RPs and SPs, on a one-to-one basis. In the virtualized case, the negotiation is done through the VNB, which reduces the resulting overhead and allows for the seamless negotiation with multiple entities at a time. However, when designing the negotiation mechanisms between the VNBs and the SPs, we should take into account a framework that reduces agency costs, thus deterring strategic behaviors which could affect the overall welfare in the system.

7 Conclusions

We propose the incorporation of WNV to the sharing framework defined by the FCC for the 3.5 GHz band. The analysis we present does not reflect regulatory and technical considerations only, it also explores additional economic factors, which play a key role for the deployment of successful sharing models.

The studied fields pose important challenges and opportunities for the sharing model we devise. In this way, we have been able to find some benefits that could stem from embedding virtualization as the technical enabler for sharing approaches. Indeed, WNV would permit to add technical flexibility to the network, which is required to accomplish the regulatory flexibility that the current regulation seeks. Additionally, we have pointed out how the addition of a new entity, the Virtual Network Builder, could allow for the distribution of the functionality that has been assigned entirely to the SAS. In the model we propose, it is likely that smaller entrants will have higher opportunities to access spectrum. This results from having a VNB in charge of aggregating the demand from multiple users and posting bids for spectrum access. In this way, the VNBs could be better competitors in the market than smaller entities alone, and their possibilities to win resources in an auction may be significantly enhanced.

We found several similarities between the characteristics and objectives of process networks and those of value networks. When adapting these concepts to our model, we expect virtualization to allow for a seamless aggregation of resources from multiple entities thus permitting to exploit the specialization of network entities at their edge. This would provide an avenue for achieving common or service-differentiated business objectives, which could lead to appealing service-based competition opportunities taking place in current telecommunications market scenarios. Overall, our analyzed framework suggests that in an environment where multiple users with varied levels and areas of specialization come together to innovate, we could actually derive opportunities instead of threats from the uncertainty of sharing.

8 Future Work

In our efforts to extend our work, we consider it important to delve into details regarding how rights are adapted to these novel sharing schemes and, how social concepts and constructs influence the deployment of accurate models. Following the study presented in [22], we expect bundles of rights to be redefined in virtualized scenarios, which will in turn have a significant impact on the model design, outcomes and evaluation.

From a social perspective, our analysis of process and value networks has shed light on the interaction of multiple entities in order to achieve common and service-differentiated business objectives. In turn, these entities will be sharing assets, which could be mapped to the *common-pool resource* definition[2]. Keeping this in mind, and as explored by Ostrom in [23], we could expect *collective-action problems* to arise under our virtualization scenarios. As pointed out by Ostrom, a possible solution is the adoption of polycentric governance approaches, which implies the development of systems of governmental and non-governmental organizations working at multiple scales. The authors in [24] have already explored the inclusion of CPR concepts and polycentric governance to the design of the SAS and how this would help define facilitating conditions for the development of successful systems. In this way, we consider that analyzing CPR and Polycentric governance notions would provide us with a richer view on how to design our virtualization system.

Acknowledgments. This work has been supported in part by the U.S. National Science Foundation under Grant 1443796.

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[2] According to [23], "[c]ommon-pool resources are systems that generate finite quantities of resource units so that one person's use does subtract from the quantity of resource units available to others. Most common-pool resources are sufficiently large that multiple actors can simultaneously use the resource system and efforts to exclude potential beneficiaries are costly".

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