Novel Spectrum Administration and Management Approaches Transform 5G Towards Open Ecosystemic Business Models

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Abstract. The ongoing 5G evolution transforming network from connectivity driven to service dominant logic will impact the stakeholder roles, ecosystem and business models. Systemic change will lower the barriers to entry and expand the ecosystem to new roles such as local operators, edge cloud services providers and resource aggregators and agents. Spectrum regulation has traditionally acted as a gate keeper of the mobile service provisioning, and lately national authorities have reacted via allocating new frequency bands and considering novel flexible spectrum administration and management methods and tools. This paper provides a comprehensive overview of the most recent spectrum regulation decisions for mobile communication networks and shows how local licensing, spectrum sharing, and unlicensed commons approaches work as novel business model antecedent. The study analyzes key spectrum antecedents for the open ecosystemic business model value configuration.

Keywords: Business model · Resource configuration · Spectrum administration · Spectrum management · 5G

1 Introduction

The fifth generation (5G) mobile communication network evolution is expanding and extending network services from mobile broadband to towards various industries with radically improved speed, capacity, time sensitiveness in connecting humans, machines and intelligence [1]. Transformation from present-day mobile network operator centric connectivity driven business [2] towards service dominant logic will be stemming from system architectural change leveraging softwarization, virtualization, network slicing, native-cloudification, novel spectrum management and service based architecture [3].

Wireless communication industry is prospecting novel and differentiating opportunities and value creation mechanisms to cope with the change and move beyond connectivity [1]. Access to human and industrial data has become central in value creation and advantage exploitation [4]. Mobile communication network and services related

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business research have concentrated on mainstream communication service providers techno-economics founded on the mobile broadband and its service variations [2]. Transition from integrator to collaborative value configuration was discussed in [5] and novel stakeholder roles such as integrator, local-operator, neutral-host and market agent discussed in [6–9]. Key technology enablers and their impacts to business were analyzed in relation to cloudification [10], web-based service models [11], and Internet of things enablement [12].

Higher mmWave frequencies and ever-increasing variety of spectrum bands with local distinct industrial use cases have further fragmented spectrum regulation [13]. Nationwide long-term spectrum assignments are complemented by local licenses [14], dynamic and shared spectrum access [15–17] and unlicensed access [18] that represents a major paradigm change in spectrum management for mobile communication networks. The US citizens broadband radio service [16] and Europe originated licensed shared access (LSA) [17] managed spectrum sharing concepts were found to enable scalability and to extend business model design towards internet business models [19]. The valuations [13] and pricing [14] of private LTE and 5G local and shared spectrum were found as essential enablers in spectrum regulation.

This interdisciplinary study seeks to cover both the technology and business perspectives. Technology view stemming from product platform with components and interfaces is focusing modularity [20] exploring economies of scale. On the other hand, business research explores sustainable growth, creation of scalable ecosystems and replicability on novel markets [21] via innovatively matching needs and resources. In a contemporary research [22] platform definition is expanded to data and algorithms and found as enabler in transforming towards network-of-services model builds. This paper seeks to answer the research question: *How could the Novel Spectrum Administration and Management Approaches Transform 5G Towards Open Ecosystemic Business Models?*

The study provides a comprehensive overview of the most recent spectrum regulation decisions for mobile communication networks and shows how local licensing, spectrum sharing, and unlicensed commons approaches work as novel business model antecedent. Furthermore, the key spectrum antecedents for the open ecosystemic business model value configuration are analyzed.

The paper is organized as follows: after the introduction, the theoretical foundation is discussed. Third section provides a comprehensive overview of the most recent spectrum regulation and analyses enabled business model scenarios. Section 4 summarizes key findings and gives suggestions for future research.

2 Theoretical Foundation

2.1 Business Model Value Configuration

The value creation, value sharing, value delivery and value capture processes and related business model concept have become essential tools in business studies [23]. Business model framework has been traditional discussed from the action angle [24]. Contemporary research [25] views business models more from value creation, opportunity exploration, and competitive advantage exploitation angles [23, 26–28]. Ecosystem driven collaboration is driven by co-creation of opportunities and advantages [29] stemming

from creation, delivery, sharing and capture of value [30]. The functioning and prosperous business models have been found to be scalable [31], replicable [32], and sustainable from business, social and environmental perspectives [33]. Growth potential builds on dynamic capabilities to scale internally and reiterate externally. The analysis of business model elements carried out in this research builds on above discussed elements as summarized in Fig. 1.

In addition to business model antecedents, the paper assess the impact of spectrum administration and management concepts from open value configuration and ecosystemic business model configurations perspectives [34]. We extend the *supply* and value chain focused focal firm centralized conceptualization [35–37] towards *demand* focused co-creation with customers, and finally considering novel *ecosystemic* model extending further to value co-capturing within the ecosystem [38]. In this paper we consider ecosystem to consists of the governance of network, platform keystones, complementors, open interfaces, innovative capabilities and resources, and modularity aspects [39].

2.2 Spectrum Management Archetypes

Spectrum management aiming at efficient utilization of the scarce national resource can be divided into three archetypes [13]: market-based mechanisms [40, 41], administrative assignment [42] and spectrum commons approach [43].

Market-Based Mechanism
The market-based mechanism [40] allows the markets to define who values the spectrum the most and should be granted the rights to use the spectrum in contrast to regulators. The most widely used mechanism is spectrum auction [44] that was the major method of assigning the 3G and 4G spectrum. Mechanism continued to limited number of individual spectrum access rights while the number of MNOs wishing to enter the market kept increasing. Furthermore, market-based approaches introduced flexibility into the market through spectrum trading and leasing options, which to date has not been taken into use widely [45].

Administrative Assignment
The traditional spectrum management approach has been administrative allocation where the national regulatory authorities (NRAs) have defined individual spectrum access rights, decided on the related rules and conditions, such as mandatory coverage obligations and assigned spectrum to cellular networks. The first generations of mobile connectivity market were in the hands of the regulators who solely command and control the number of licensees and decided on the admittance of any new entry. In the course of time, NRAs opened the mobile communication market for competition with state-owned monopolies that resulted in several benefits [46]. The administrative allocation faced growing criticisms on the fairness as continues to be deployed for 3G and 4G spectrum assignments in some countries [47]. Lately novel administrative methods have been revisited through regional and local licensing approaches [18].

Spectrum Commons
The unlicensed commons approach differs from the administrative allocation and market-based mechanisms as it allows market entry to a variety of wireless systems potentially deployed by a variety of stakeholders based on shared access to the spectrum instead of individual spectrum access rights [43, 48]. Traditionally, the unlicensed approach has not attracted mobile operators whose deployment was based on individual access rights providing exclusive access. On the other hand, in the 4G and 5G era to cope with exponentially growing data traffic, the cellular community has introduced 4G and lately 5G technology variants for unlicensed access in certain bands to share the bands with the other users [18]. The spectrum commons approach has been the source of success for wireless local area networks deployed by any stakeholder.

3 The Business Perspective of Spectrum Administration and Management Enablers

This section discusses the novel spectrum administration and management methods as enablers for the business models transformation. 5G spectrum management frameworks are already in place or are being defined for making dedicated spectrum available for wideband public and private networks, the main use case being MBB. The focus is on harmonized spectrum bands identified to international mobile telecommunications (IMT) in the Radio Regulations of the International Telecommunications Union (ITU) and covered by standards of the Third Generation Partnership Project (3GPP). Such bands are globally the major licensed bands for mobile communications. Suitable license exempt bands are also widely available, and some shared spectrum has been released and is being considered. The selected exemplary cases in this paper present spectrum management approaches in several countries on 1800 MHz, 2.3 GHz, 2.5 GHz, 3.5 GHz, 4 GHz, and 26/28 GHz licensed frequency bands considered for LTE and 5G. The license exempt usage of the 5 GHz Radio Local Area Network (RLAN) bands, 6 GHz, and 60 GHz is also addressed. Information on studied spectrum management frameworks have been collected both from public national regulatory authority (NRA) sources and interviews. The spectrum administration and management frameworks are analyzed based on assessment framework [18] developed for the novel industrial use cases and summarized in (Table 1).

3.1 Market Based Mechanism

Nationwide Individual Authorizations
The dominant approach used worldwide for awarding licenses for 5G public mobile networks is auctioning the individual authorizations where the associated nationwide spectrum assignments are awarded exclusively to the highest bidders. This approach has been and is used by most countries for authorizing most of the 4G and 5G networks and assigning the associated spectrum [49, 50]. The market based national licensing supports the traditional MNO-centric closed business model.

The market based approach has been used for authorizing nationwide deployments in 5G bands in countries like Denmark (700 MHz), Finland (3.4–3.8 GHz), France (700 MHz), Germany (3.4–3.7 GHz), Hungary (3.4–3.6 GHz), Ireland (3.4–3.6 GHz, 26 GHz), Italy (700 MHz, 3.6–3.8 GHz, 26 GHz), Spain (3.6–3.8 GHz), Sweden (700 MHz), UK (3.4–3.6 GHz), Canada (600 MHz), US (600 MHz, 24 GHz, 28 GHz, 37 GHz, 39 GHz, 47 GHz), Australia (3.6 GHz), Hong Kong (3.3 GHz, 3.5 GHz, 4.9 GHz), Korea (3.5 GHz, 28 GHz). The auctions are also planned to be used for 5G band authorizations e.g., in Austria (700 MHz), Belgium (3.6–3.8 GHz, 26 GHz, 32 GHz, 40 GHz), Finland (26 GHz), France (3.4–3.8 GHz, 26 GHz), Poland (700 MHz, 3.6–3.8 GHz) Spain (700 MHz, 26 GHz), Sweden (3.5–3.7 GHz), UK (700 MHz, 3.6–3.8 GHz), US (38 GHz, 47 GHz), Canada (3.5 GHz). In most cases the auctions are used for awarding nationwide licenses with exclusive usage rights, but they have also been used without full exclusivity. For example, in Italy, the 26 GHz band was auctioned employing an innovative Club Use licensing regulatory framework.

The* 26 GHz *in Italy (ITA* 26 GHz*)

The Italian regulator AGCOM auctioned the 26 GHz band as part of a 5G multi-band auction [51]. All five lots of 200 MHz from the 26.5–27.5 GHz were awarded to the five highest bidders, one lot for each [52]. The 26 GHz licenses were awarded on a nationwide basis without coverage obligation and fully exclusive usage rights. Instead, the licenses are based on a so-called "*Club Use*" model, in which each licensee can use the available spectrum in areas where the other licensees do not use it. Once the actual licensee wants to deploy its networks in the area, the individual rights of use on the acquired spectrum will prevail. This mechanism is intended to increase the efficiency of the overall use of the 26 GHz band. Due to the propagation characteristics of the band, the coverage areas are expected to be small, and therefore the regulation allows wide freedom for the licensees to agree on building the coverage in collaboration. There was low interest towards the 26 GHz auction, probably at least partly due to the Club-use model, as the MNOs prefer dedicated exclusive bands.

Regional/Local Individual Authorizations

It is also possible to use market based mechanism for awarding the regional/local individual authorizations and the associated spectrum assignments to the highest bidders. Due to regional/local coverage areas this approach leads to geographical sharing, which may lead to higher overall spectrum use efficiency. But depending on the sizes of the areas and the size of the country, the number of auctioned regional licenses may be large, and yet the areas larger than required for actual network deployments.

The* 3.5 GHz *Citizens Broadband Radio Service for PAL use (US CBRS PAL)

Citizens Broadband Radio Service (CBRS) system made 3.55–3.7 GHz band available in the US [16]. The band and its users consists of three layers: incumbents users (tier 1), individually authorized priority access license users in 3.55–3.65 GHz (PAL, tier 2) and general authorized "license by the rule" access users (GAA, tier 3) in the whole band.

In the PAL spectrum auctions the band was divided into 10 MHz channels. Maximum PAL spectrum holding is four times 10 MHz in any service area for 10 years with a renewal option. The PAL authorizations are required to ensure interference protection

to the incumbents. The novelty of PAL regulation is that it allows the leasing of unused spectrum. Moreover, general authorized access (GAA) users are allowed to access the unutilized incumbent or PAL licensed spectrum slots. The spectrum management is based on the spectrum access system (SAS) that grants available spectrum for the base stations (CBSDs) while ensuring protection to higher tier users. The scalability and flexibility of the CBRS system enables new entrants and business models: PAL licenses allowing for acquiring exclusive access, GAA offering a low cost option for non-critical services and additional option between the PAL and GAA. The leasing rules for CBRS PAL spectrum provide also a potentially lower cost option for industrial enterprises to lease exclusive spectrum at their facility utilizing the SAS provided spectrum marketplace for PAL spectrum. In August 2020, the PAL auctions bidding concluded and raised a total of $ 4,5 Billion in net bids, with 228 bidders winning a total of 20,625 licenses. Top winners included Verizon, Dish, and several the top US cable companies. The auction was unique in a way that many qualified bidders were non-traditional auction participants thanks in part to the smaller size of the licenses. Utilities, rural service providers, universities and others joined wireless and cable service providers in the bidding.

3.4–3.8 GHz *in Austria (AUT* 3 GHz*)*
The bands 3.41–3.6 GHz and 3.6–3.8 GHz were auctioned in early 2019 [53]. The country was divided into 6 urban and 6 rural regions, so that there was one urban region covering one or two of the major cities inside each rural region. Technical conditions were those defined by the EU. The auction resulted in three MNO's getting access to 100–140 MHz of spectrum each, over all regions, thus building up nationwide coverage, while the remaining spectrum was all sold to other organizations in 5 out of 12 regions. However, a portion of the spectrum remained unsold in 7 regions. In two regions the unsold amount was 10 MHz, in one region 40 MHz, and in four regions 60 MHz in each. Therefore, the regional auctions did not result in efficient overall use of the band over the whole country. One reason may be that the cost of spectrum even in the rural regions ended up high, e.g., the cost of 30 MHz sold in one rural region was 1.8 million €, and the cost of 40 MHz in another rural region was 4.3 million € [54].

3.2 Administrative Assignment

Nationwide Individual Authorizations Spectrum was traditionally assigned to MNOs through administrative assignment, in so called beauty contest. The currently dominant method is market-based approach through auctions, but the administrative assignment is still used in a few countries, such as Japan and China for awarding exclusive nationwide spectrum assignments. In April 2019, The Japanese Ministry of Internal Affairs and Communications (MIC) assigned spectrum in the 3.7, 4.0, 4.5 and 27/29 GHz bands through a beauty contest to four mobile operators, assigning dedicated sub-bands for each. This approach can also be used to assign shared spectrum. China has recently awarded the band 3.3–3.4 GHz to three mobile network operators on a shared basis. It is the first time China makes IMT spectrum available for shared use. The band is available nationwide, but only for indoor use, which makes sharing straightforward.

Regional/Local Individual Authorizations
The dominant authorization procedure for issuing regional/local licenses is administrative assignment. The most common approach is first-come first-served, used especially in cases where the number of licenses in a certain area/location is limited by co-existence requirements. In other cases, the approach can be all-come all-served, when the number of licenses is not limited. Usually there is a yearly fee for the spectrum usage, either a fixed amount, or depending on coverage, bandwidth and possibly some other parameters. Some frameworks offer protection from harmful interference between the regionally/locally deployed networks based on coordination by the NRA or by technical means, while in other cases the approach is uncoordinated, leaving avoidance of harmful interference to the licensees, or to be covered by technical requirements. By employing this regulatory framework, the NRAs intend to respond to the foreseen local and regional spectrum requirements of the verticals.

Shared Access Mobile Bands in the UK (UK Shared)
The UK regulator Ofcom has made spectrum in four shared access bands locally available through Shared Access licenses. The bands are 1.8 GHz, 2.3 GHz, 3.8–4.2 GHz and the 26 GHz [55]. The access is individually authorized, allowing operation in a certain location, for some of the bands only indoors. The applicants need to specify the bands they would like to access, as well as the planned locations. There are two types of licenses, low power license (per area license) and medium power license. The low power license allows the users to deploy a required number of base stations in a circular area of a 50 m radius, while the terminals are covered by the same license. The medium power licenses are available mainly for deployments in the rural areas. The licenses are assigned on a first-come first-served basis and the access is coordinated by Ofcom to ensure avoidance of harmful interference between the users. This approach can provide certainty for the spectrum access and a possibility to provide QoS. The yearly license fees are cost based administrative fees, reflecting Ofcom's cost of issuing the license. The licenses are valid for an indefinite duration.

Local Access to Unused Spectrum of the MNOs in the UK (UK Local)
The Local Access license provides a way for users to access spectrum licensed to MNOs in locations where the MNO is not using its full spectrum [56]. All bands assigned to MNOs are candidate bands. The Ofcom will issue a Local Access license if the new usage does not cause harmful interference to the MNO, and the MNO does not raise justified objections. The technical conditions will be considered on a case by case basis. The default license period is 3 years, and there is a one-off license fee of £950. There is a possibility for longer term or shorter term license. There is a lively 3GPP technology ecosystem for all MNO bands and equipment widely available, but the license will also allow deployment of other technologies.

The* 2.3 GHz *in Finland (FIN* 2.3 GHz*)
The 2.3 GHz band is identified globally for IMT and the European regulation for mobile networks is in place. However, in Finland and many European countries the band is used for other services than MBB, and re-farming would be impractical. The LSA concept developed by the European conference of postal and telecommunications administrations

(CEPT) could facilitate shared use. The regulation and standards exist [17], but the public mobile network operators have not shown interest towards accessing the band. As there are unused spectrum resources, the sub-band 2.3–2.32 GHz is being allocated in Finland to mobile service on a secondary basis and designated to private mobile networks, such as private LTE networks [57]. The specific 20 MHz band may provide the required spectrum for verticals, but its usability still depends on the geographical locations of the incumbent usage, i.e. wireless cameras that need to be protected from harmful interference. The 26 GHz band will be made available in Finland for nationwide 5G deployments as three 800 MHz bands. The sub-band 24.25–25.1 GHz is not to be auctioned and will be reserved for local private and industrial 5G deployments.

The* 2.6 GHz *in France (FRA* 2.6 GHz*)

The band 2.575–2.615 GHz was made available for private networks in 2019 [58]. The regulator's data base based web page shares the availability of frequencies to facilitate the application process. Furthermore, the applications are made available for the public reviewing. The local licenses have a maximum bandwidth of 40 MHz and are granted for 10 years. The yearly fee is 17 k€ per 5 MHz for the 100 km^2 coverage area. The relatively high fee may limit the possibilities of deploying some small scale innovative applications over a small area. The available bandwidth is likely to limit the number of networks in the same location. France has opened the 26 GHz band for 5G trials platforms, authorized for the period of three years. Some of the trials are led by verticals and those trials are focusing on industrial/private applications. The ACREP will determine the regulation for the band after the 3 year trials and based on the nature of the trials, regulation allowing for local deployments can be expected.

The* 3.6 GHz *Wireless Broadband Service in Canada (CAN WBS)

Wireless broadband service (WBS) band 3.65–3.7 GHz is allocated to fixed and mobile systems for Tier 4 service areas across Canada [59]. The service area specific annual fee for a "all-come-all-served" license depend on the population density, ranging from 250 CAD in rural areas up to 21 kCAD in Toronto. The licensees share the band within the service area and are obligated to self-manage the coexistence facilitated by the regulator hosted spectrum management system (SMS) database showing the status of licenses and related radio characteristics. WBS spectrum is easily accessible, but depending on the location, the coordination that is left to the licensees may be an extra burden. ISED studies the need for reorganizing the band and updating the regulation, but no short-term changes are expected as the WBS band is widely used.

The* 3.5 *and* 3.7 GHz *in the Netherlands (NL* 3 GHz*)

The 3.41–3.5 GHz and 3.7–3.8 GHz bands are used by a military satellite earth station in the northern part of the country. In order to protect the incumbent usage, those frequencies cannot be used for mobile services in the northern part of the country. Outside of the above discussed restriction zones, base station specific 40 MHz bandwidth licensed are available for local private networks, under specific operational regulation [60]. To date, more than 150 licenses have been issued and in some areas the bands are getting fully occupied. As the authorization process is based on the first-come first-served principle, in most popular areas it may not be possible to get a license. For the moment, the licenses

are temporary, as there are plans to remove the military earth station from the band and reorganize the use of the whole C-band around 2022. It seems that one option under consideration would be to re-farm the local networks to the 3700–3800 MHz band as done in Germany and planned in Sweden. The C-band is one of the European pioneer bands for 5G, and the reorganization of the band could release most of the C-band available for public 5G networks in an efficient manner.

The* 3.7 GHz *in Germany (GER* 3.7 GHz*)

The band 3.4–3.7 GHz was auctioned in 2019 for public mobile networks whereas the band 3.7–3.8 GHz was made available for individually authorized local private assignments [61]. Applications can be submitted any time; eligibility is related to the land ownership or right of use. The license duration is 10 years, and the licenses are transferable. There is a fee depending on the assignment bandwidth, license duration and the category of the deployment area [62]. Deployment in densely populated area is more expensive than a deployment in a sparsely populated area. The locations and the area can be defined by the applicants. The approach is service and technology neutral. Efficient use of spectrum is required, with a principle use-it-or-lose-it. There are technical requirements to ensure that no harmful out-of-band interference is created. In addition, operators of geographically adjacent networks are obliged to negotiate agreements between them. If this fails, the regulator BNetzA may define measures to ensure efficient and interference free use of spectrum for all affected operators. This could include definition of a maximum field strength limit at the edge of the coverage area. 74 licenses have been awarded by BNetzA by September 2020. Furthermore, there are also around 50 experimental assignments.

The BNetzA assumes that also the 26 GHz band could be used by various local 5G applications [63]. The main characteristics of the proposed regulatory framework are similar to the regulation of the 3.7 GHz band. Usage of general authorization was not felt possible due to demanding requirements for incumbent protection in the band. The 26 GHz band could complement the 3.7 GHz band by providing much wider bandwidths for shorter range communications required by many industrial applications.

The* 3.8–4.2 GHz *in Belgium (BEL* 4 GHz*)

The Belgian regulator BIPT intends to allow 4G and 5G private networks in the 3.8–4.2 GHz band [64]. The licenses will be local, and not transferable. The maximum amount per licensee is limited to 40 MHz, which is to facilitate sufficient overall capacity for multiple licensees in one location/area. A local network license is based on an applicant defined circular zone with minimum radius of 100 meters, allowing base stations inside the zone. Terminals are allowed outside the circular area as long as connected to one of the base stations that inside the licensed circular zone. The BIPT makes a compatibility study for the applications, determines the technical conditions and assigns the frequencies. There is an initial fee for each new application and annual fees per area, to facilitate high number of small cells inside the licensed area. The BIPT assumes this to become a typical 5G deployment scenario. The licenses are expected to become available in 2021.

The* 28 GHz *Shared Spectrum in Hong Kong (HK* 28 GHz*)
In the 27.95–28.35 GHz band, four 100 MHz channels are shared geographically for the local wireless broadband services and assigned by the "first-come-first-served" rule. Real time voice communications to and from public network is not allowed. The license duration for the maximum 400 MHz bandwidth within the maximum area of 50 km^2 is 5 years with 5 year extension option [65]. In the concept, the potential co-existence issues are self-managed by the peer licensees. The regulatory authority decides upon the amount of granted spectrum, based on the application. Annual spectrum license fee depends on the number of base stations, number of devices and allocated bandwidth.

The* 28 GHz *in Japan (JPN* 28 GHz*)
The Japanese regulator targets at enabling industrial automation across verticals via "Local 5G" spectrum initiative for non-existing mobile operators [66]. The 28.2–28.3 GHz was allocated first and will be followed by the band 28.3–29.1 GHz till end of 2020, depending on the sharing studies with the satellite incumbents. The licensing is based on the land ownership and in case of the land or property is not owned by the applicant, allowed service will be fixed wireless only. There is a fee for base stations and for terminals. The Kanto Bureau of Telecommunications granted Japan's first private 5G radio station provisional license in the band 28.2–28.3 GHz band in February 2020.

3.3 Spectrum Commons

The license exempt bands, spectrum commons, allow operation of compliant radios under a general authorization, without an individual authorization. Technical or regulatory means are employed to facilitate co-existence with other applications in the band.

The* 3.5 GHz *CBRS for GAA Use in the Unites States (US CBRS GAA)
The general authorized access (GAA) users can access the portions of the CBRS band 3.55–3.65 GHz that are unused by the incumbents and the PAL users and the portions of the band 3.65–3.7 GHz that are unused by the incumbents [16]. The GAA users can access the bands on an unlicensed, shared basis. The amount of GAA spectrum may vary based upon variations incumbent and PAL usage, and the unlicensed GAA users may experience harmful interference from higher level users and other GAA users. The spectrum access system (SAS) will identify suitable spectrum for the base stations (CBSDs). Operation under GAA on the CBRS band could be suitable for new entrants and certain business models, because GAA usage allows for a very low cost option for non-mission critical services.

The* 5 GHz *Radio Local Area Network
The ITU radiocommunication sector has defined the 5.15–5.35 GHz and 5.47–5.725 GHz for wireless access systems including radio LANs [67]. The most common authorization framework deployed globally is a general "unlicensed" authorization. Because several incumbents use those bands, a number of technical and operational requirements have been defined by the ITU-R and in the standardization to avoid interference to incumbents. European telecommunications standards institute standardization allows system deployment in the EU, in additional countries covered by the European conference of

postal and telecommunications administrations regulation, and several additional countries outside of Europe, recognizing the EU CEPT regulation. Similarly, the unlicensed national information infrastructure (U-NII) radio band 5.725–5.850 GHz in US has been allocated and specified to unlicensed RLAN type of devices [68] and allocated by several national regulators globally for similar application. LTE unlicensed (LTE-U), licensed spectrum access (LAA) and Multefire are 3GPP 4th generation (4G LTE) based standards were developed to access the license exempt spectrum while being fully compliant with the RLAN standards and regulation. To complement the 3GPP 5G standardization, in the current release 16 the 3GPP has defined 5G new radio unlicensed (5NR-U). Depending on the regulatory framework, the so far low allowed maximum transmit power in the band 5.15–5.35 GHz may limit the coverage area to small cells.

The* 6 GHz *Radio Local Area Network

To meet the exponentially growing need for wireless "last mile" capacity and to cope with congested 2.4 GHz and 5 GHz RLAN bands, there are several studies and recent allocations on expanding the RLAN use to bands above 5 GHz. In the US, additional 5.925–7.125 GHz band, divided into four segments, has been allocated for licensed exempt devices with similar technical regulatory conditions than in the 5 GHz spectrum [69]. Two segments allow only low-power operations while other two 6 GHz segments require employment of automated frequency coordination (AFC) system to protect incumbent services via providing automated frequency availability information. European regulatory study on wireless access system is focusing on 5.925–6.425 GHz spectrum. Radio local area networks are allowed with limited transmit power indoor with strict emission requirements to protect large installed base [70]. The UK regulator Ofcom will make the band 5.925–6.425 GHz available for RLANs and other related wireless technologies on a license-exempt basis, enabling indoor use and very low power (VLP) outdoor use [71]. A regulatory challenge for large scale availability of the 6 GHz band may be that it is not identified for IMT by the ITU-R, and the technical regulatory requirements are likely to become different in different regulatory frameworks, but on the other hand the 3GPP has developed a 5G NR-U standard to the 6 GHz band as part of Release 16. The upper part of the band is on the agenda of the WRC-23.

The* 26 GHz *in Australia (AUS* 26 GHz*)

The Australian regulatory authority is in process of allocating 24.25–27.5 GHz band for fixed and mobile applications in 2020 [72]. Several authorization schemes are foreseen for different parts of the band: class license (license exempt), apparatus license and spectrum license. The 24.25–24.7 GHz segment will become available countrywide for private broadband indoors without interference protection. The 24.7–25.1 GHz spectrum will be licensed to indoor and outdoor wireless broadband using the apparatus licensing, limited to private property. Furthermore, the 25.1–27.5 GHz will be allocated to wide-area wireless broadband in 34 metropolitan areas and regional centers via auction. The wide range of authorization options can support deployment of innovative 5G applications.

***The* 60 GHz**

Spectrum around 60 GHz has been widely available for several years for license exempt data networks. The exact bands depend on the country, but in general the 60 GHz band offers 5–14 GHz of spectrum for very high bitrate data, video and audio applications that supplement the capabilities of Wireless LAN devices. Regulation exists for operation in the band 57–71 GHz in the US [73] and in Europe in the band 57–64 as short range device (SRD) and in 57–71 GHz as wideband data transmission system [74]. The attractiveness of the band was further increased by the recent WRC-19, which identified the band 66–71 GHz globally for IMT. Currently, both IEEE and ETSI standards exist, and the 3GPP is in the process of preparing a NR-U standard for the band as part of its Release -18. The band is suitable for very high bitrate transmissions due to the up to several GHz bandwidths. The frequency range does not offer wall penetration, but free space ranges up to 300–500 m can be reached with highly directional antenna.

Table 1. The summary of the spectrum administration and management approaches.

Framework	Market based	Administrative	Commons
Auctioned 5G	Nationwide		
JPN 4 GHz	Nationwide		
ITA 26 GHz	Nationwide		
US CBRS	Regional (PAL)		Local (GAA)
AUT 3 GHz	Regional		
UK Shared		Local	
UK Local		Local	
FIN 2.3 GHz		Local	
FRA 2.6 GHz		Local	
CAN WBS		Regional, shared	
NL 3 GHz		Local	
GER 3.7 GHz		Local	
BEL 4 GHz		Local	
GER 26 GHz		Local	
FIN 26 GHz	Nationwide	Local	
HK 28 GHz		Local, shared	
JPN 28 GHz		Local	
RLAN 5 GHz			Nationwide, shared
RLAN 6 GHz			Nationwide, shared
AUS 26 GHz	Regional	Local	Local, shared
60 GHz			Nationwide, shared

3.4 Open Ecosystemic Business Antecedents

In 5G ecosystem, stakeholders have a wide variety of novel assets and resource as well as needs that should be orchestrated and configured optimally in order to co-create, share and co-capture value. In identifying, matching and bridging needs and resource companies can take multiple roles in the ecosystem [75]. Novel spectrum management approaches could assist the progression of value-creation processes and transformation from closed integrator and collaborator models towards ecosystem-focused transaction and bridging models.

In the *integrating* resource configuration, a company source all the resources utilizing traditional value-chain logic. This closed business model has been widely deployed by incumbent mobile network operators leveraging nation-wide licensed spectrum in offering mobile communication services.

In a *collaborator* model, a focal firm completes its offering and creates value via orchestrating and configurating partner's complements. Mobile broadband business has utilized this model in bundling connectivity services with media content and commerce-based mobile banking service offering as well as in the mobile virtual network operator (MVNO) model. Furthermore, emerging spectrum trading, leasing and partnering models enabled by majority of NRAs are emerging in offering dedicated services to verticals.

A transactional marketplace builds on a digital multi-sided-platform that extends and reduces friction to access resources through intelligent matching. From spectrum management perspective, the first phase NRA acting as a focal orchestrating firm for local licensing. In the recently commercially opened, US CBRS spectrum sharing model spectrum management and transactional platform is outsourced to SAS operators.

In bridge resource configuration a platform creates value via connecting the needs and resources of unconnected stakeholders without owning the virtualized resources. CBRS PAL auctions concluded in August 2020 will open new opportunities for a bridge provider via a SAS marketplace matching spectrum supply and demand.

Exploring and exploiting *opportunities* and *advantages* can be seen to motivate ecosystemic interaction from a dynamic capability perspective. Novel opportunities were found in utilization of local spectrum, unlicensed spectrum offering and shared spectrum marketplace in offering connectivity services to growing industrial automation segment. *Value* creation, delivery, sharing and capture are considered the key elements of a functioning business model. Transformation from tardy nation-wide multi-million spectrum licensing towards distinct local valuation and pricing, automated low transaction cost administration and sharing economy-based spectrum sharing are creating new value. As the mobile broadband business has started to even out, industrial automation across verticals is seen as a new value capture opportunity with higher willingness to pay based on quality and service level agreement. Timely access to affordable exclusive spectrum based on use case and business needs will lower entry barrier and create advantage particularly to novel stakeholders like micro-operators. As summary, enablers for 5G growth via *scalability* and *replicability* were found in radio standardization at 3GPP and IEEE, zero touch automation and transaction platforms. Furthermore, compared to traditional spectrum administration and management, novel local licensing and sharing were found essential contributors to spectrum resource *efficiency* and *sustainability*. In addition to

discussed enablers, there are a few framing elements that would need to be considered in applying novel approaches into 5G systems. In the mobile operator business, network deployment details are considered business critical information that many novel database based spectrum administration and management concepts request. In additions to ever increasing variety of spectrum bands, fragmented regulation due to national policies and differentiating incumbent usage can seriously reduce scalability and replicability of the related technology platforms. Furthermore, co-existence and interference management between neighboring operators calls for new technologies. Figure 1 summarizes how 5G business exploiting novel spectrum management can be built on novel business opportunities, value generation and competitive advantage that have positive strategic consequences on scale, reproduction, and stability. Stemming from 5G system level value driver summarized in Fig. 1, spectrum administration and management enablers can be seen to transform business model value-configurations towards open and ecosystemic as depicted in Fig. 2. In addition to spectrum commons, both the administrative local licensing and CBRS concept were found to democratize the tools of production through access to affordable spectrum, cutting the costs of consumption by democratizing distribution with web-scale automatization and connecting supply and demand via NRA database and further utilizing automated SAS marketplace.

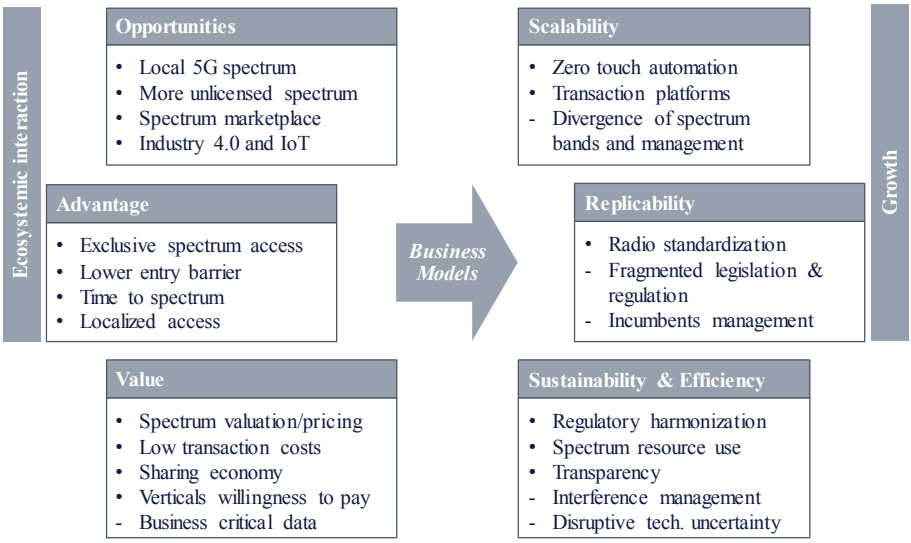

Fig. 1. Indicators of value and performance enablers (·) and framing elements (-) of the future 5G business exploiting spectrum management enablers.

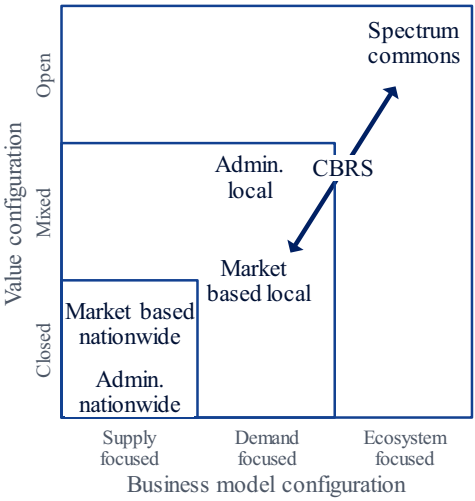

Fig. 2. Spectrum administration and management enablers in the evolutionary 5G business model [34].

4 Conclusions

This research explored the future of radio frequency administration and management utilizing ecosystem and business model frameworks. The ecosystemic open value configuration business model was found as key antecedent to enable wider cross-industry entry and involvement. scenario. The results indicate the importance of the transactional spectrum marketplace as a trigger for business model change. Local licensing and spectrum sharing methods and technologies have potential to transform the spectrum asset orchestrations and market. Theoretical implications of the study pave the way to utilize value and ecosystemic business model configuration in analyzing novel mobile business. In the paper the recent status of traditional spectrum administration and novel management approaches are reviewed through the lenses of evolutionary 5G business models focusing on ecosystem and growth antecedents.

Future research on the local licensing and database-based dynamic spectrum access approaches could consider stakeholder and ecosystem analysis. Further work is needed to validate novel spectrum administration and management technology and regulatory enablers in order to reduce concerns related to system reliability and trustworthiness.

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