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Value of the spectrum for local mobile communication networks: Insights into awarding and pricing the 5G spectrum bands

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Abstract

Spectrum management decisions made by the regulators aim at maximizing the value of spectrum, its efficient utilization and benefits to the society. A major debate in spectrum management globally is currently focusing on 5G spectrum bands and their awards. In fact, several countries have recently made their first 5G spectrum awards decisions, which will have a long-term impact on the mobile communication market. This paper analyses recent 5G spectrum decisions from the spectrum valuation view point and discusses the emerging role of local 5G networks to serve the needs of different vertical sectors. Special attention is put on the awarding and pricing of 5G spectrum and recommendations are given on new pricing mechanisms that take into account the emergence of local 5G networks by different stakeholders. The results highlight the divergence in the spectrum management approaches that the regulators in different countries have taken where the first 5G spectrum decisions have continued to strengthen the mobile network operator (MNO) market dominance while the most recent planned decision aim at opening the mobile market to new local entry through local spectrum access rights.

1. Introduction

There are high expectations set on the next generation mobile communication networks (5G) as a major infrastructure for digitalization [EU 2016]. 5G is expected to be a key enabler for a pervasive transformation in local mobile communication networks and allow the emergence of many new innovative businesses across multiple sectors. The essential success factor for 5G deployment is the availability of the radio spectrum. It is a scarce natural resource the efficient management of which calls for a thorough understanding of its value. The success of the new 5G services and solutions will depend on the appropriate valuation of the spectrum – as part of their awarding and pricing.

In general, spectrum management aims at maximizing the value of the spectrum [Bazon & McHenry 2013], its efficient utilization and benefits to the society. Spectrum management decisions will play a critical role in meeting the expectations set for the 5G networks, which are specially envisaged to be tailored to new local vertically specific service delivery [Matinmikko 2018; Matinmikko-Blue 2018]. While there is a global commitment to make the new spectrum available for 5G, the detailed spectrum assignment decision making of granting access rights to those, who wish to deploy the networks, remain a national matter as discussed e.g. in [Anker 2017]. Prior spectrum decisions for 4G networks especially in Europe have followed a similar path of defining nationwide

long-term spectrum licenses and granting them through auction mechanisms for a small number of mobile network operators (MNOs) [Beltran & Massaro 2018; El-Moghazi et al. 2017]. A wide range of spectrum assignment approaches ranging from exclusive licensing to regional and local licensing or license-exempt operations are currently being considered for the 5G bands by the national regulators, which calls for a fresh look into spectrum valuation [Markus & Molnar 2017; Beltran & Massaro 2018; El-Moghazi et al. 2017]. These decisions need to take into account the conflicting stakeholder views on who needs the spectrum while there is a lot of uncertainty on the future market developments.

Some countries have already assigned spectrum access rights for the deployment of 5G networks especially in the 3.5 GHz band, while others are in the process of defining the spectrum awarding rules and criteria as summarized in [Matinmikko-Blue et al. 2019]. In their 5G spectrum awards decisions, the regulators face a new situation, where location-specific services and higher carrier frequencies give a rise to new local network operator models for vertical-specific service delivery [Matinmikko 2018; Matinmikko-Blue 2018]. While the first 5G spectrum decisions have followed a rather traditional approach of long-term wide-area exclusive spectrum licenses to a few MNOs with prices determined by different auction mechanisms [MINTC 2018; Matinmikko-Blue et al. 2018; Matinmikko-Blue et al. 2019], several countries are now considering the assignment of local spectrum access rights for the deployment of 5G networks by several different stakeholders [BNetzA 2018; PTS 2018a]. How to award these rights and, moreover, how to price them based on their value, is a yet unresolved but an extremely important question to study by both regulators and academics.

This paper addresses the emergence of local 5G networks into the mobile communication market for vertical-specific service delivery from the spectrum valuation viewpoint. The paper focuses on the spectrum assignment of the 5G bands and aims to answer the following research questions: **What are the current valuation principles used for awarding the 5G spectrum for mobile communication networks in different countries? and thereby What new pricing mechanisms could promote the establishment of local 5G networks?**

This research expands the authors' prior research on the valuation of the 5G spectrum that derived a framework of elements for the value of the spectrum [Matinmikko et al. 2018; Matinmikko-Blue et al. 2019]. The research presents the different spectrum awarding mechanisms and discusses them from the viewpoint of the establishment of local 5G networks. The research addresses the recent or upcoming 5G spectrum awarding decisions in different places including Australia, Canada, Finland, France, Germany, Hong Kong, Italy, Japan, Netherlands, United Kingdom, United States of America and Sweden.

The rest of this paper is organized as follows. Literature review on spectrum management approaches and the value of spectrum is presented in Section 2. The specifics of mobile communication networks and especially 5G are discussed in Section 3. Pricing aspects in general and specifically in spectrum management are presented in Section 4. Recent 5G spectrum awards are reviewed in Section 5. Finally, recommendations towards innovative pricing for 5G spectrum are given in Section 6, followed by conclusions in Section 6.

2. Spectrum management approaches and the value of spectrum

Spectrum management decisions aim at maximizing the value of spectrum. Several classifications exist to characterize different spectrum management approaches. In general, spectrum management approaches have evolved from administrative allocation towards market-based mechanisms and the unlicensed commons approach, which are described next.

Administrative allocation

Administrative allocation is a command and control method where the regulator uses its position to define who can use the spectrum and under which rules and conditions. The major focus in administrative allocation is on minimizing the harmful interference between different spectrum users. This is done at the expense of efficient use of the spectrum by leaving margins in frequency and spatial domains to ensure that different wireless services remain free from harmful interference. Typically, incumbent spectrum users' rights are protected when considering new entry. This has resulted in situations where the existing spectrum users lack the motive and incentives to enhance their efficiency of spectrum use or give up on the spectrum for other usage. Spectrum sharing typically does not play a role in administrative allocation.

Market-based mechanisms

Market-based mechanisms are nowadays used by many regulators to assign access right for the provisioning of commercial wireless services. Market-based mechanisms [Beltran 2017] define spectrum property rights and assign these rights through market mechanisms to those requesting for them. The most common market-based mechanism is the use of auctions [Cramton 2013]. A variety of auction models have been developed and used by the regulators, but their common challenge is the design of proper auction mechanism and parameters that would lead to a desired outcome [Kuroda & Forero 2017]. Thus, market-based mechanisms only work if they are carefully designed, taking into account the complex relationships between spectrum management decisions and resulting market outcomes which is extremely difficult. Another form of market-based mechanisms is the right for the licensees to resell their spectrum access rights which exists in many countries. However, these secondary spectrum trades occur seldom in practice.

Unlicensed commons approach

The unlicensed commons approach differs from the administrative allocation and market-based mechanism by allowing unlicensed access for different stakeholders to deploy wireless devices. The unlicensed commons approach has opened the market for new entry by allowing typically low-power wireless devices to operate in the band based on spectrum sharing without the need of individual licenses through a set of rules and conditions approved by the regulator. The unlicensed commons approach has resulted in many benefits to the society and has become an essential spectrum management approach for regulators. The benefits include for example wide variety of wireless systems available to be deployed by different stakeholders, faster time to market, new innovations, and it has become the major delivery mechanisms for mobile traffic in indoors.

Spectrum sharing

Spectrum sharing allows two or more radio systems to operate in the same band. A number of spectrum sharing techniques and models have been developed to facilitate different levels of priority for systems in accessing the spectrum. Based on profound spectrum sharing work in policy, standardization and research building on existing Dynamic Spectrum Access (DSA) standards Television White Space (TVWS) [Ofcom 2015], novel licensing-based sharing models have recently emerged the Licensed Shared Access (LSA) [ECC 2014] from Europe and the Citizens Broadband Radio Service (CBRS) [FCC 2014] and Automated Frequency Coordination (AFC) [FCC 2018] from the US. The two-tiered LSA builds on scale and harmonization in traditional exclusive licensing-based regulation and standardization. It also leverages existing assets and capabilities of Mobile Network Operators (MNOs). The CBRS on the other hand, extends dynamics through an opportunistic third license by the rule layer, fine-grained census tract -based spectrum allocation and sensing [Yrjölä et al. 2015].

Value of spectrum

Understanding the value of spectrum is at the heart of regulators' spectrum management decisions when attempting to maximize the value of spectrum [Bazolen & McHenry 2013]. Prior work on the value of spectrum has focused on defining engineering value, economic value and strategic value. Engineering value [Markendahl et al. 2010] is concerned with the achievable cost savings in infrastructure from the availability of additional spectrum. Economic value of spectrum goes further and considers the potential value arising from the use of the spectrum through specific services which take into account the future profits that could be earned. Strategic value is concerned with the stakeholder's control of its market position through spectrum assignments.

Authors in [Matinmikko-Blue et al. 2018; Matinmikko-Blue et al. 2019] highlighted the stakeholder view on the spectrum value and identified the following elements of spectrum value: offered services, spectrum allocation and assignment, location-specific characteristics and band-specific characteristics. Moreover, they emphasize that the value of spectrum is stakeholder specific – the regulator, the incumbent spectrum user and the entrant, have highly distinct view on the value of spectrum, to name a few. Services offered in the band have a big impact on the value of the band in terms of the different expected future profits along with their role in the society which may not have direct monetary value. The spectrum allocation and assignment methods define the conditions, parameters and restrictions on the use of the spectrum, which influence the value of that band. Location-specific characteristics are becoming increasingly important as different areas have different profitabilities driven by both revenues and costs. Finally, band-specific characteristics arising from the physical propagation characteristics, development of the band's ecosystem, and incumbent spectrum users significantly impact the value of the spectrum. It is then in the responsibility of the regulator to derive the proper contents for the elements of spectrum value in their spectrum awards decision making.

3. Mobile communication networks and spectrum awards

Cellular mobile communication networks play a crucial role in people's day to day. The mobile communication business ecosystem has traditionally been dominated by a small number of big MNOs. Regulators have had a significant influence on the competitive situation in the mobile communication market through their spectrum awarding decisions that have given the access rights to the MNOs [Lundborg et al. 2012] This has implied a risk to competition if the spectrum allocations favor the leading operators to secure their strong market positions.

Over the past decade, spectrum auctions have become the major mechanism for regulators to assign rights granting rights to use the mobile spectrum which has limited the potential licensees to those who can afford high license fees and fulfill coverage obligations. While auctions introduce objectivity to the process [Cave & Pratt 2016; Cramton 2013], they may favor existing players. In some cases, the regulators have set coverage obligations to the deployment of the mobile network generations and the MNOs have had business motivation to fulfill the requirements. There always though remain spots with poor quality of service, which is acceptable due to spectrum characteristics.

However, there is still room for discussion if everything has been done to avoid the phenomena of poor service. In particular, the dialog conducted during the past years with many verticals like industry, health care and real estate actors, reveal that some of the verticals may have suffered in economic or safety manner seriously about weak quality of service by the MNOs. When having been introduced the concept of vertical specific service provider, many of those actors have confirmed the need for evolvement and welcomed the novel approach. The Industrial Internet of Things (IIOT) is a major component for next generation wireless systems and is being studied by many organizations globally. The International Telecommunication Union (ITU) [ITU 2015] identifies Industry Automation and Smart home/building as key usage scenarios of International Mobile

Telecommunications (IMT) for 2020 and beyond. The European Commission is focused on this critical need under the banner “Industrie 4.0” and notes [I4.0 2019]: “*Industry 4.0 refers to the intelligent networking of machines and processes for industry with the help of information and communication technology.*” The Industrial Internet Consortium (IIC) is focused on how industrial assets like things, machines, sites and environments, can be connected to business professionals and processes, and currently has in excess of 200 members from various industrial sectors from across the globe [IIC 2019]. Contemplating this discourse it reminds about the imperative needs of business life and empowers to initiate actions to redefine the value of spectrum.

MNOs that have already invested in the infrastructure and prevent competitors from entering the market [Lundborg et al., 2012]. In addition to spectrum decisions, regulators’ have set requirements for interconnection and interoperability for the services, which has shaped the ecosystem for the benefit of end users and allowed a smaller network holder to gain access to the users and benefits of the larger network [Feasey 2015] and prevented big firms to from charging too much or denying access. This has been an important step in opening the market for competition

Most recently, the development of 5G networks is primarily addressing enhanced mobile broadband service delivery but also targeting vertical specific service delivery in specific locations. This has raised the question of who would be the right stakeholders to operate the local 5G networks that aim at serving specific verticals. Research on locally deployed 5G networks by different stakeholders has introduced novel business models. Authors in [Ahokangas et al. 2018; Ahokangas et al. 2019] present three generic business models for local 5G networks. The key to the success of locally deployed 5G networks is the guaranteed availability of spectrum in specific locations which calls for new spectrum assignment approaches to 5G compared to prior generations as discussed in [Matinmikko et al. 2018].

4. From spectrum valuation to spectrum pricing

Spectrum can be seen as a valuable business asset. In particular, spectrum should be considered as an intangible asset rather than a physical good despite its physical nature. In general, the value of an asset or liability can be cost, market or income based. Intrinsic valuation methods, such as the much-used discounted cash flow model, revolve around the present value of an asset's expected future value. These methods do not rely on any direct observation, as opposed to relative value models, such as the analysis of the prices of corresponding competing assets in the market. In practice, intrinsic and relative valuation are often used to complement each other, but the valuation of intangible assets may be quite problematic. [Dolgui & Proth 2010]

Value in business markets can be defined as the “*perceived worth in monetary units of the set of economic, technical, service, and social benefits received by a customer firm in exchange for the price paid for a product offering, taking into consideration the available alternative suppliers' offerings and prices*” [Anderson et al. 1992], pointing to product-related value and relationship-related value elements. There is also a trade-off among product, service, know-how, time-to-market, and social benefits, as well as price and process costs in a supplier relationship, as perceived by key decision makers in the customer's organization [Ulaga & Eggert 2005]. For valuation, [Töytäri, Rajala & Alejandro 2015] find four key dimensions in industrial settings: strategic, operative, social and symbolic. however, it is important to separate valuation and pricing as concepts as their relationship may not be straightforward and depend on several factors such as stakeholder roles, their objectives and situational/contextual factors, among other things.

Valuation and pricing in wireless communications research

In the wireless communications domain, the traditional research approach has been competitive pricing to find appropriate level of valuation for the spectrum, as demonstrated in a myriad of papers examining with game theoretic models' optimum spectrum prices or market equilibriums mostly in oligopolistic situations [Niyato & Hossain 2008b]. This has worked considerably well for markets dominated by a limited number of MNOs competing over a scarce spectrum resources and facing only a moderate level of risk due to regulators' aim to maintain a certain level of competition in the consumer dominated connectivity markets to reach societal benefits. The competitive pricing thinking has boiled down to service provisioning [Niyato & Hossain 2008a] With 5G, this thinking becomes disrupted, as the increasing number of local networks cannot be considered as perfect markets nor an oligopoly. Rather, they resemble a sharing economy with co-opetitive (i.e., parallel competitive and and cooperative relationship between parties) characteristics. Although there is some research that uses game theoretic approaches in co-opetitive situations, especially in the context of cognitive networks, the dynamic pricing approaches assumed in game-theoretic models have severe limitations in local network contexts where the asymmetry in bargaining power between the local and non-local stakeholders may create high entry barriers or lead to harmful forced choice or lock-in situations to smaller players. Furthermore, due to the small value and illiquidity of licenses for private networks, auctions are often not a viable method of pricing. Small number of buyers makes auctions inefficient [Tonmukayakul 2008].

Within the context of the evolution of vertical specific local 5G mobile communication networks, it is obvious that spectrum pricing would need to be developing towards relative rather than intrinsic only pricing, and that spectrum valuation approaches based on several different elements will pave a road to multidimensional, holistic pricing schemes. An especially interesting and important question is, how to implement dynamic demand-based pricing in spectrum markets. The question remains which would be the characteristics upon which the spectrum base price varies: types of markets from niche verticals to horizontal services, kinds of uses from ad hoc to very long lasting, characteristics of users from individuals to corporations and machines, usage areas, and time scales required for spectrum use.

Toward a novel pricing-based valuation scheme for local spectrum

Traditionally, three pricing strategies are identified in the literature: cost-based, competition-based and value-based pricing [Hinterhuber, 2008]. If cost-based pricing builds on cost accounting data, competition-based pricing utilizes anticipated or observed prices of competitors or relevant benchmarks in the industry [Hinterhuber 2008]. Value-based pricing, in turn, is customer focused and is based on the difference between perceived benefits and sacrifices of the customer [Töytäri, Rajala & Alejandro 2015]. Practically, price is defined between customer's and supplier's perceived benefits. Pricing at the market level is related to the value differential of an offering to that of competing or supplementary offerings. At the actual transaction level, it involves managing the implementation of the earnings. Correspondingly, pricing can be seen from a strategic or a tactical level. There exist many different pricing strategies, such as operations-oriented pricing in which supply and demand are sought to be optimally matched, customer-oriented pricing to make use of cross-selling opportunities, and relationship-oriented pricing to create and maintain relations with the current or wanted new customers. One way is to divide pricing into two main categories, favoring price discrimination, i.e., segmentation, or exploiting complementarities. [Johnson 2005]

Pricing tactics deal with how to set and maintain prices in different situations, over time and across customers. There exists a large number of pricing tactics, but many if not most of them are demand based. Dynamic demand-based pricing is increasing especially for digital offerings, but also for physical products and services accessible

through digital platforms. Its basic feature is that the price may vary quite much and very often. A longer-known approach is multidimensional or holistic pricing, in which the price is not determined by a single number but consists of several different dimensions. [Indounas 2009] If such dimensions are brought to the micro level, prices are customized for the needs of very small market segments or uses, and the result comes close to the dynamic demand-based pricing.

Value-based pricing [Töytäri, Rajala & Alejandro 2015] and innovation pricing [Hinterhuber & Liozu 2014] might provide fresh starting points for spectrum valuation. Both value-based and innovation pricing reject the idea of a zero-sum game prevalent in competitive pricing approaches and apply plus-sum game ideology. In value-based pricing the starting point is customers' perceived value. Innovation pricing, in turn, differs from competition-based pricing in that it does not assume an oligopoly situation. In innovation pricing the objective for pricing may be segmentation, performance, market expansion or transformation, to create a metrics, or participation. In innovation pricing zero price is a special case. Innovation pricing may also be implemented with various tactics such as revenue management that varies pricing, contingent pricing, bundling, individualized pricing, flat fees, creative discounting, or psychological pricing. Spectrum pricing should follow demand and be based on transparent methods and easily available data. The demand for consumer services such as mobile broadband has traditionally followed population density, but this is not necessarily true for industrial vertical demand and will not price the licenses to match the highest willingness to pay. This calls for a new innovative measure for the industrial demand that reflect the differences between industries [Kokkinen et al. 2019].

To summarize the discussion, this paper presents a valuation-pricing framework to understand spectrum pricing (Fig. 1) that looks at the types, dimensions, aims and strategies of valuation and pricing. Value of an asset should exceed its price and costs in the long run to maintain its benefit to the society as a whole. Valuation and pricing are intertwined, but separate concepts, and when discussing the value or price of spectrum, we need to consider them separately for both spectrum provider's (regulator) and spectrum user's (operator) point of view. Valuation of an asset based on demand and supply may be either intrinsic or relative, but nevertheless needs to consider strategic, operative, social and symbolic dimensions on both supply and demand sides. It should be noted that both sides may seek either protection of existing markets or creation of new markets and follow a selected strategy, either cost-based, market-based or income-based valuation of spectrum.

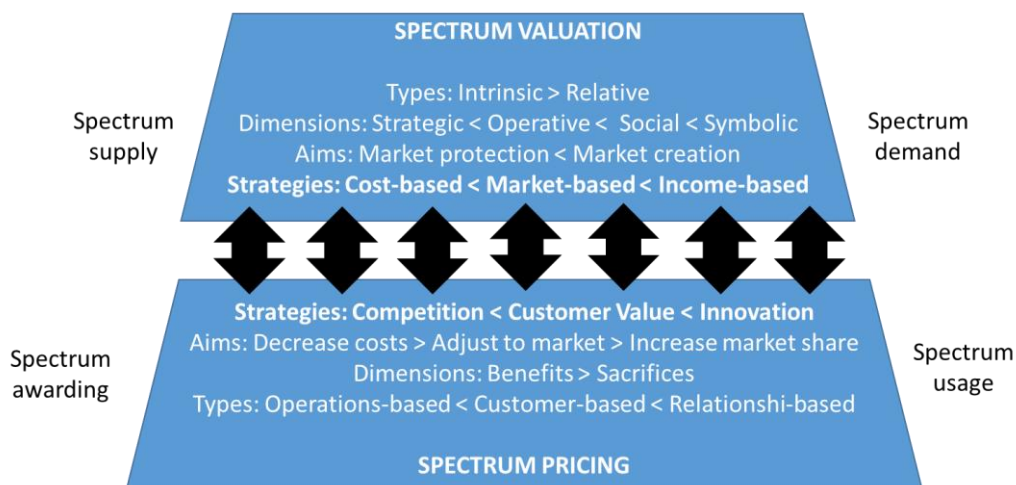


Fig. 1. Spectrum valuation-pricing framework.

Regarding the pricing perspective, pricing of awarded and used spectrum may be operations-based to seek optimal match of to-be-awarded and to-be-used spectrum, customer-based to exploit spectrum users' needs, or relationship-based to ensure continuity by looking the dimensions of benefits and sacrifices. Basically, pricing aims at decreasing costs, adjust to markets, or increase market share. These are reflected in the three basic pricing strategies: competition pricing, customer value -based pricing and innovation pricing.

In the case of vertical local networks, we see a clear need for experimentation to find adequate value and price for spectrum, whether dedicated or shared. Traditionally regulators have considered oligopolistic markets where competition and social benefits are sought in awarding spectrum to use. Because wireless networks business can in many respects regarded as a mature market, it has been important to safeguard national interests and confine to protecting existing markets rather than creating new markets – which we see as a new important target in the case of local 5G networks. On the pricing side, a closer examination of the local players perceived value and innovation potential needs to be considered. Thus, experiments with innovative pricing schemes and tactics should be conducted.

5. Case studies on recent 5G spectrum awards

Regulators face a completely new situation in their attempt to answer the question of how to award the 5G spectrum bands. There is a wide variety in the propagation characteristics and thus resulting deployment models between the first major 5G bands considered including 700 MHz, 3.5 GHz and 26/28 GHz. Several countries have already assigned the first 5G spectrum access rights while other countries are in the process of defining the rules and conditions.

In the following, an overview of recently conducted or planned 5G spectrum awards in different countries is presented, with a special focus on the spectrum awarding and pricing aspects and how these decisions facilitate the emergence of local 5G networks. The selected areas include Australia, Canada, Finland, France, Germany, Hong Kong, Italy, Japan, Netherlands, United Kingdom, United States of America and Sweden. They were selected to provide a comprehensive representation of the current 5G spectrum landscape, but they do not present all 5g spectrum awards globally. As the 5G spectrum awarding processes are in different stages in the different countries, some of the presented information is subject to change.

Australia

The Australian regulator ACMA released its preliminary views on the future use of 26 GHz band following a consultation hold in September 2018. The lower part 24.25-25.1 GHz is proposed for development of industries and private use under different schemes. Sub-band 24.25-24.7 GHz will be class-licensed for wireless broadband limited to private property (including domestic, industrial, business, commercial and government) and restricted to indoor use only (Australia-wide). Sub-band 24.7-25.1 GHz will be class-licensed for indoor and outdoor use limited to private property (including domestic, industrial, business, commercial and government) for wireless broadband (Australia-wide) as well as for Australia-wide apparatus licensing with fixed point-to-multipoint or mobile (base station with service area) in nature deployments. The objective is to allocate 26 GHz during Q3/Q4 2020. Price-based allocation, i.e., auctions will be used for spectrum licenses where the highest demand exists, in the most densely populated regions. [ACMA 2019]

Canada

In Canada, the national regulator ISED has designated the band 3650-3700 MHz for wireless broadband service (WBS) and fixed and mobile systems with no restriction on eligibility [ISED 2010a; ISED 2010b]. Renewable one-year licenses are issued on all-come all-served basis for Tier 4 service areas for a service area specific annual fee.

The band is shared between all the WBS licensees within the service area, and the licensees are expected to cooperate to identify and resolve possible interference problems by themselves. Tier 4 comprises 172 localized service areas across the country. License fees depend on the population of the Service Area, fees ranging from 250 CAD in rural areas up to 21 kCAD in the Service Area of Toronto. To assist in facilitating cooperation and coordination, ISED has developed a publicly accessible spectrum management system database (SMS) showing both current license and site-specific data. Licensees are required to up-load their information to the database at least six weeks before putting a site to service and keep it up to date. In addition to coordination between the WBS licensees, they must ensure that no harmful interference is created towards incumbents deployed in the adjacent band and meet coordination distance requirements from the Canada-US border. Deployed technologies include WiMax and LTE, which have been adjusted to comply with the specific requirements of the band. A public consultation was conducted in 2018 [ISED 2018], which addressed among other things the WBS band future regulation needs, e.g., via possibility to leverage the US CBRS concept for the spectrum management.

Finland

Ministry of Transport and Communications in Finland awarded the first 5G spectrum band, the 3410-3500 MHz band, in 2018 [MINTC 2018]. A total of three country-wide licenses, 130 MHz each, were awarded through a simultaneous multiround auction without coverage obligations. The total price paid for the licenses was 78 M€ and all three existing MNOs got a license. No new entry occurred and no spectrum was set aside for entrants or local deployments. The band was cleared from prior incumbent fixed wireless access usage. The actual price paid for the spectrum (78 M€) remained close to the start price of the auction (65 M€). Regarding local vertical specific service delivery, the licensees are obliged to lease their spectrum if they do not offer a local vertical specific network in a given location if requested. However, no other constraints were set on this resulting in a situation where the license holders can always offer a service and thus fulfill the requirement. While Finland was among the first countries in Europe to award 5G spectrum, the spectrum management decisions strengthened the market dominance of the existing three MNOs by given them each 130 MHz of additional spectrum without.

France

In France, the national regulator ARCEP opened the portal for enterprises to apply for 2.6 GHz TDD spectrum in May 2019 [ARCEP 2019]. ARCEP targets the band for a local professional mobile network that address the specific connectivity needs of certain businesses and organizations, like verticals in the infrastructure sectors: *"... usually designed to stay operational even in the event of a major crisis and may offer special features, such as the ability to make group calls. They can be deployed either to ensure the security of a site, or as a business tool for companies wishing to have a customized communication system, for example for the management of passenger transportation, water or energy networks, and for the internet of things."*

The aim is to grant access to blocs of 10, 15 or 20 MHz, in limited geographical areas and for maximum ten years licenses. Each applicant would have to specify the requested coverage area and justify the spectrum needs within that area. Compliance with the technical conditions of the EU would be required [EC 2008], e.g. the use of TDD would be required and the maximum field level at the edge of coverage area is restricted. The pricing will be dependent on the size of the area licensed to the enterprise user with a general principle of ensuring a balance with pricing for a MNO having a national license. The formula will be the same as the one in the existing decree [ARCEP 2007] adjusted for the distinct area size. Initial yearly license fee is planned to be 18 000€/100 km² per 5 MHz.

Germany

In Germany, the band 3400 – 3700 MHz auction process is ongoing for public mobile networks, and the application procedure for the 3700 MHz – 3800 MHz range for regional and local assignments will be initiated after the end of the auction in 2019. The process allows applying for regional and local assignments not only at the time when the new regulatory frameworks comes to force, but also at a later date, flexibly and in line with the demand. There is currently a large amount of regional and local assignments in the 3400-3700 MHz band, with licenses expiring latest at the end of 2022. Those networks will be relocated to the 3700-3800 MHz band. The German regulator BNetzA has published the planned application procedure and the rules for the band 3700-3800 MHz [BNetzA 2018]. Access to the band is based on application and requires an individual authorization from BNetzA. The duration of the transferable license with spectrum fee for an applicant defined area is 10 years. In a first phase, applications for local frequency use can be submitted for the company's own real estate or premises, large industrial parks and trade fair grounds as well as agricultural land. In this context, it is also conceivable that several property owners, e.g. of a commercial area, submit a joint application for a frequency allocation for the entire area. Operators having current access to licensed spectrum in 700 - 3700 MHz already are only eligible for a temporary access, in case there are unused parts in the 3700-3800 MHz band. There are rules also for outdoor deployments to ensure that no harmful interference is created outside the defined coverage area. The approach is service and technology neutral, though TDD is the only allowed duplex technology, and networks must be synchronized. National roaming is not mandated but allowed. Efficient use of the assignment is required, also through-out a region, with a principle use-it-or-lose-it.

Hong Kong

Hong Kong's Office of the Communications Authority (OFCA) has released a spectrum roadmap for the next three years, through which the agency aims to award key 5G frequencies. Due to the ample supply of spectrum in the 26 GHz and 28 GHz frequency bands, it will be assigned administratively. A total of 3,700MHz of spectrum will be assigned for the provision of territory wide large public mobile services, and a total of 400 MHz of spectrum will be set aside for the provision of 5G services to specific groups of users on a geographically shared 1st come - 1st served bases with no network rollout obligations. According to the rules [OFCA 2018] aggregated network coverage by each applicant should not exceed 50 km². Licensing period for a 100 MHz bandwidth will be 5 years with one-time renewal option. OFCA will invite applicants in 2Q19. The annual spectrum use fee is \$1080 per MHz.

Italy

At 26 GHz band, auctioned in 2018, Italian regulator AGCOM introduced a "Club use" model in which each licensee can dynamically use all the awarded spectrum (up to 1 GHz) in areas where frequencies are not used by other licensees. To this aim, licensees can stipulate commercial reasonable and non-discriminatory agreements, proportionally sharing the costs. Each licensee has the pre-emptive right in favor of its assigned lot or lots. Licensees can assign to a trusted third party the task of managing the uses to avoid harmful interference as well as the access scheduling.

Licensees must provide access (wholesale capacity) to other non-Telco players, e.g. service providers for the development of 5G services. In case requester asks for access in areas already covered, the access is provided by the covering operator, and in case access is requested for an area not yet covered, licensees handle the request collectively or through the trusted third party. Network deployment can be entrusted to a third party. The operator which is granted access cannot resell pure TLC services. In closed lands with public attendance (i.e. ports, airports, stadiums, arenas, cinemas, theatres, national parks, museums, metros, etc.), where the radio

sites building must be authorized by the land owner/manager, the licensee(s) implementing coverage has to offer access to the other licensees in order to avoid foreclosure mechanisms and duplication of investments. [AGCOM 2018]

Japan

The national regulator MIC has reserved bands 4.6-4.8 GHz and 28.2-29.1 GHz for private local 5G access in limited areas. The MIC is planning to open 28.2-28.3 GHz for Private 5G use from August 2019. Other bands 4.6 – 4.8 GHz and 28.3 – 29.1 GHz will become available in limited area to avoid interference to incumbent and will be discussed later with the targeted legislation is 2020. Private network owners may obtain the radio station license by themselves or ask others to obtain radio stations license. Local 5G bands are not supposed to be used for mobile network operator's coverage or service compensation. Local 5G spectrum can be used within private premise indoors and outdoors. Fixed Wireless Access type of application is allowed in non-private premise or non-private premise included in the coverage. 5G regulatory technical requirements and conditions are valid, and transmission power may be adjusted at the time of radio license application to meet coexistence issue with other local 5G network users. [MIC 2019]

Netherlands

The bands 3410-3500 MHz and 3700-3800 MHz are available for local broadband networks, including private LTE networks in the southern part of the country [Agentschap 2019]. In order to protect the incumbent military satellite earth stations, those bands cannot be used for mobile services north from the Amsterdam – Zwolle line, while the rest of the C-band is available for commercial, nation-wide mobile use with restrictions on the emitted power towards north [Staatscourant 2011]. The authorization process is based on the first-come-first-served principle and the deployment and operation of networks requires a license from the regulator. At present, the base station-based licenses with the maximum bandwidth of 40 MHz are temporary, expiring on 2022 for the higher band and on 2026 for the lower band. The band is widely deployed with e.g., more than 150 licenses issued in industrial areas, like the Rotterdam harbor. There are plans to re-allocate the earth station incumbent, and to re-farm the local networks to the 3700 – 3800 MHz band echoing Germany and Sweden. The Netherlands license price is fixed 633 € per base station.

United Kingdom

The UK regulator Ofcom has published a consultation on shared access in the 3.8-4.2 GHz band, in a portion of the 2.3 GHz band (2390-2400 MHz) and in the 1800 MHz shared spectrum (1781.7-1785 MHz paired with 1876.7-1880 MHz) [Ofcom 2018]. The Ofcom proposes a single authorization approach for all three bands to provide spectrum for local networks in locations unused by licensed incumbent services. Moreover, the consultation includes also a regulatory proposal to allow access to the unused parts of the bands awarded to public mobile networks. Two types of individually authorized licenses are defined: a low power license allowing operation of a low power base station within a 50-meter radius circle, and a medium power license for operating a medium power base station in a rural area. The Ofcom assess for each application the interference to and from other licensees in the band, based on coordination methodology and parameters proposed by them and make the assignments on a first come first served basis. This approach would provide certainty for the spectrum access and a possibility to provide QoS. The license fees would be cost based administrative fees, charged annually on a per area based or on a per base station basis, amount depending on the used bandwidth: the original proposal being £80 per 10 MHz. In the current proposals the Ofcom would deal with coordination between the licensees, but they intend to explore the potential for introducing dynamic spectrum access (DSA) in the proposed three shared access bands.

United States

The US regulator FCC proposed a novel CBRS approach in the 3.5 GHz band to allocate up to 150 MHz low-cost shared spectrum in the 3550-3700 MHz band [FCC 2015]. The spectrum currently has existing tier 1 incumbents who are given priority and protection from interference within the band from lower tiers. Besides incumbents, the FCC has setup two additional tiers of users: tier 2 priority access license (PAL) users and tier 3 general authorized access (GAA) users. The rules provide two paths for local spectrum, PAL and GAA. According to the recent final FCC rules [FCC online], the PAL spectrum will be auctioned off in smaller regional areas, in roughly 3200 counties, for ten years licenses with possibility of renewal. In comparison, to date many spectrum auctions in the US are done over 416 Partial Economic Areas that has made it expensive and not viable for an enterprise to acquire. The cost to acquire a single 10 MHz PAL will be determined by a spectrum auction but should be reasonably priced compared to other cellular spectrum auctions. Furthermore, the rules allow for a single PAL licensee to hold up to four channels in any licensed area at any given time, providing up to 40 MHz of spectrum protected from interference [FCC online].

The final rules also allow the PAL holder to lease their PAL spectrum beyond their deployment coverage but within their PAL area. Moreover, PAL may be partitioned and disaggregated. Thus, in a local industrial area a PAL holder may lease to other neighboring enterprises within their PAL area use of their PAL spectrum. A second path for local spectrum in the CBRS band is to use 80 MHz of opportunistic, licensed by the rule GAA spectrum. Additionally, spectrum not currently used by an incumbent or by a PAL holder is available for GAA users on a shared basis. For both GAA and PAL, the base stations (CBSDs) must register with a SAS (Spectrum Access System) and request a spectrum grant. The SAS will attempt to find suitable spectrum for the CBSD and ensures higher tier users are protected by lower tier users, though the un-protected GAA spectrum may have significant interference from other GAA users.

Extension to 3.45-3.55GHz is under consideration in FCC but rules could be different from CBRS. Furthermore, part of 3.7-4.2GHz is also possible.

Sweden

Swedish NRA PTS concludes the *Preliminary study prior to future assignment of frequencies for 5G* in May 2018 after the public consultation with the authority's intents for the assignment of frequencies for 5G. PTS proposed new assignment of the entire 3.4-3.8 GHz band to be carried out in 2019, with 300 MHz to be assigned as national block licenses in 3.4-3.7 GHz by means of a selection procedure, and 100 MHz 3.7-3.8 GHz to be assigned in the form of local block licenses in order to satisfy the demand for national block licenses as well as provide opportunities for smaller local stakeholders to become established. The new licenses in the band will be associated with conditions that TDD as the duplex method and if there is more than one license holder, there are significant advantages with introduction of synchronization that limits interference and leads to a high level of spectrum efficiency. The proposed assignment form and frequency use echoes the solution for the 3.4-3.8 GHz band chosen by the German regulatory authority and is positive from an international harmonization perspective. Questions concerning block size, how local licenses should be assigned and priced are examined further in connection with the ongoing assignment process. [PTS 2018a]. Current policy on spectrum pricing method in Sweden for local 3.7 GHz, low subscriber deployments offer very affordable deployments [PTS 2018b]. Currently, the decisions are under preparation and not concluded yet.

6. Recommendations for 5G awards towards innovative pricing

There is a wide variety of spectrum management approaches that are applicable in different setups considering the national specifics. While the role of market-based mechanisms has increased over the years in mobile communication spectrum awards, there is still lots to do to make it function. The major market-based mechanism so far have been the use of auctions with country specific rules and conditions whereof some have created artificial scarcity on spectrum to raise higher revenues and others have used auctions in the process where administrative allocation would have led to the same outcome. From other market-based mechanisms, very few spectrum trades have occurred after the auctions despite them being possible in Europe for a rather long time period indicating that the realization of a functional spectrum market is still far ahead.

Regulators in their 5G spectrum awards summarized in Section 5 have considered the specifics of 5G networks and especially the emergence of local 5G networks in highly versatile ways. The development of spectrum awarding and pricing mechanisms for the new 5G bands whose characteristics differ highly from the traditional cellular bands, calls for a fresh look into the problem, based on proper valuation of the spectrum. The traditional spectrum awarding mechanisms used for mobile communication networks approaches based on auctioning of country-wide licenses and pricing based on the number of users simply does not work for verticals and other specific, dynamic use contexts and situations.

The problem is how to implement the location-based pricing of radio spectrum for private LTE and 5G networks efficiently, simply, transparently, and fairly for the areas which are not dominantly residential [Cramton & Doyle 2015]. A particular problem is how the location should affect the price. The short run efficiency is that existing network resources are put to their best use in satisfying demand, and long-run efficiency is that long-run network investments are made to satisfy demand at least cost. Simplicity means that participants can express preferences simply and effectively, they experience straightforward incentives, and their risks are reduced. In transparent spectrum pricing, the rules map bids into outcome clearly and unambiguously. Participants know why they won or lost and understand why their payments are what they are; and the participants are able to confirm that the market rules were followed. Fairness translates to equal opportunity, possibility for all potential participants to have access to the market rules, and to rules that do not inappropriately discriminate among parties.

For the future, there is a need to increase flexibility of operations through the spectrum management actions. Flexibility especially in terms of the operational area and time frames to gain access to the spectrum and the time period for operating the wireless systems is urgently needed since the value in different applications is different. Some of the key elements to be taken into account include such entirely new types of “users” as machines, very small geographical areas, complementary or competing roles of different use contexts – for example factories vs. shopping malls vs. mass events vs. rural agriculture, and especially time scales of network use for which spectrum is required.

One of the greatest shortcomings of the traditional spectrum valuation and pricing logic has been the retrenched role of innovation. New spectrum has been allocated based on oligopolistic logic of competition, where a limited number of operators have received the spectrum with a minimum risk that does not foster new market creation or transformation, and even less innovation of new types of services and businesses. Local verticalized settings could be a source of innovative new services that could create new markets and transform existing markets toward new growth. However, because local and verticalized network the spectrum needs may vary considerably based, e.g., on the type of activity, length and peaks of activity, amount and quality (interference) of spectrum needed, types of users (human, machine), and value add created, dynamic needs-based or customer value -

based pricing should be developed and utilized. Dynamic needs-based pricing could also be used to maintain the value of spectrum rather than just assume a certain initial configuration and level of value.

Conclusions

The mobile communication market is going through a transformation in becoming the key infrastructure to support the digitalization of various sectors of the society. This development gives rise to novel local operator models to deploy and operate 5G networks to complement the existing MNOs' offerings. This development is heavily dependent on the regulator's spectrum decisions which shape the market and resulting environment for competition and innovation.

Our analysis on recent 5G spectrum awards presented in this paper has shown that there is a high divergence in the approaches that the national regulators have adopted in their 5G spectrum decisions to take into account the new technical and business characteristics of the 5G networks. Some countries have rushed to auction the first 5G bands to the existing MNOs with nation-wide license but without any coverage obligations using a market-based mechanism in a situation that resembles an environment for administrative allocation. Other countries are in the process of allowing the establishment of novel 5G local operator businesses through making local 5G spectrum licenses available through administrative allocation mechanisms. This indicates that the value of spectrum is understood and treated very differently in the different countries in 5G spectrum awards.

In summary, while the very first 5G spectrum decisions have strengthened the MNO dominance in the mobile market in some countries, other countries are adopting new spectrum assignment methods that allow the emergence of local 5G networks by different stakeholders. This change demonstrates the need for understanding of the value of spectrum in a new way from innovation and competition perspectives and calls for the need to develop new pricing mechanisms that take into account the variety of applicants for the spectrum access rights beyond the traditional MNOs.

There could be other regulatory issues to address when operating private networks, including: other licensing requirements for operation of telecommunications systems and any non-spectrum license or authorization fees payable. Further, cross-disciplinary work is needed to create simple regulatory processes to reduce the cost and minimize the complexity of use of spectrum for private network, and to provide clear rules and guidance aimed at those wanting to supply and operate private LTE and 5G networks.

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