# Spectrum Broker Service for Micro-operator and CBRS Priority Access Licenses

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**Abstract.** This paper discusses a spectrum broker service for micro-operator and Citizens Broadband Radio Service (CBRS) Priority Access Licenses (PAL). The spectrum broker service provides a marketplace for selling and leasing of spectrum resources. The micro-operator licenses are regional, and possibly temporal, mobile network spectrum licenses for a confined service area like for a factory, a campus, or a hospital. CBRS opens the 3.5 GHz band for Dynamic Spectrum Access (DSA) in the US. PAL is the middle priority level license in CBRS. The paper introduces a new service model for spectrum brokering. The required functionalities of the service are described, and a new automated spectrum pricing model is proposed for the broker service.

**Keywords:** Spectrum broker · Dynamic Spectrum Access · Micro-operator CBRS

## 1 Introduction

Traditional spectrum allocation for Mobile BroadBand networks (MBB) is mainly done in the primary market where the government authorities sell long term licenses by auctions. While these auctions have many benefits and are accepted as the standard method, they still lead to inefficient situations in particular circumstances. The demand for the spectrum can change rapidly and drastically due to factors such as changes in traffic demand, spectrum applications, and technologies. However, the static long term licenses do not adapt to these changes [1]. This leads to situations where the licenses are not held by the parties that value them the most. Another problem that Berry et al. [1] recognize is that the packaging of licenses to large blocks leads to oligopolies where there are only few large license holders. The winning bidder might not need all bundled licenses so parts of the spectrum remain unused. Additionally, restricted competition and static licenses hinder new innovation.

A solution to this problem is to establish a secondary market for the licenses. Cramton and Doyle [2] state that an open access market for spectrum would increase competition and make the process more efficient, transparent, fair, and simple. Chapin and Lehr [3] found that there are three enablers for market liquidity in the secondary spectrum access market: available spectrum by increasing achievable Quality of Services (QoS) and hence, demand, and low transaction costs and risks. On the other hand,

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Xavier and Ypsilanti [4] discuss issues related to introduction of secondary markets. The following relevant concerns were highlighted: uncertainty regarding the future primary allocations leading to incorrect estimations of spectrum scarcity and value; lack of information on available spectrum; risks of increased interference; coordination, harmonization, and controlling mechanisms; anti-competitive conduct, in particular concentration of spectrum and hoarding; disruptive effects on end users; and ability to achieve public interest objectives. Based on this, Ballon and Delaere [5] suggest the use of coordinating or enabling mechanisms and entities contributing to efficient spectrum management through providing information to stakeholders, interference mitigation, frequency harmonization, combating anti-competitive behavior, and pursuing public interest and consumer protection. Governmental or privately operated automated systems can contribute to regulation through monitoring compliance with policies and regulations, act in case of violations, and support public policy objectives. This potentially results lower cost, more efficiently utilized spectrum, and embedded management, and further helps to define the 'rules of the spectrum game' for co-operative interactions contributing to business aspects.

There are many proposals of real-time secondary marketplaces where capacity is auctioned according to current demand, for example [6]. Yoon et al. [7] examined the effects of three different frameworks, direct trading, auction. and brokerage for the secondary spectrum use and considered changes in market conditions and institutional limitation. They suggested that direct trading optimizes social welfare, considering current technical, economical and policy factors, while more complex trading mechanism may not yet achieve the optimal benefits due to implementation costs. In these studies, marketplaces were mainly designed for liquid licenses. However, this paper answers the research question: *How to facilitate the exchange of spectrum resources that are used for applications such as micro-operator licenses or Priority Access Licenses (PAL) in Citizens Broadband Radio System (CBRS)* [8]. These licenses are often *illiquid micro licenses*. Thus, we introduce a non-real-time marketplace for buying and leasing both exclusive and shared access to spectrum. The main function of the marketplace is to allow fast, convenient, and low-cost exchange of local licenses. If there is a high demand for a particular micro-license, sellers can use auction instead of a buy now price. Auctions can be used to find the equilibrium price but they do not work as efficiently if there are only few buyers [9]. It is reasonable to assume that the number of buyers is relatively small in micro licensing cases, because the licenses are local and they benefit only few buyers.

Additionally, this paper examines the pricing of illiquid micro-licenses. The price of liquid licenses can be determined for example by auctions or by comparing the sales prices of similar licenses. However, when there are not enough buyers or sellers, market based methods are not reliable. The valuation can also be done by evaluating factors such as the potential economic benefit of the license and the opportunity costs of alternative options. However, this is a labor-intensive method and might not be economically worthwhile when considering the size of the micro licenses. This paper introduces an automatic valuation method for these small, illiquid licenses.

First, this paper will consider the uses for a secondary market. Then, it will describe the key functions of the marketplace such as listing, buying, and valuation. It then proposes a few revenue models for the marketplace and describes some of the existing

open source platforms that could be used for developing the marketplace. Finally, the paper concludes that the proposed marketplace could be a viable method for allocating the illiquid micro licenses.

## 2 Brokering Business and CBRS

The proposed marketplace facilitates the secondary exchange of small, illiquid licenses. It could be used to allocate spectrum resources for the local networks used by clients such as event organizers, education facilities, and manufacturing companies. Matinmikko et al. [10] introduce a new local operator model for the deployment of ultra-dense small cell radio networks in specific locations. In this concept, a micro operator buys or leases spectrum access from the current license holder such as a large network operator. They then provide the required service and infrastructure for a client that needs a local network solution. The proposed marketplace allows micro operators to gain access to spectrum conveniently.

Another example, which could benefit from this kind of secondary marketplace is CBRS Priority Access Licenses [8]. The Federal Communications Commission (FCC) [11] licenses for the PAL layer users will be assigned via competitive bidding. They are allowed to operate up to a total of 70 MHz of the 3550–3650 MHz spectrum segment, and they are protected from General Authorized Access (GAA) interference. A PAL non-renewable authorization is for a 10 MHz channel in a single census track for three years, with the ability to aggregate up to six years up-front. To ensure availability of PAL spectrum to at least two licensed users in the highest demand areas, licenses will be permitted to hold no more than four PALs in one census track at once, and no licenses are granted if there is only one applicant, except in rural areas. The PAL layer may cover critical access users like utilities, Internet of Things (IoT) verticals, governmental users, and non-critical users e.g., Mobile Network Operators (MNOs) and Wireless Broadband Service (WBS) providers on the 3650–3700 MHz band after the final five-year term. PALs are auctioned to the licensee within their service area on a census track basis but the specific channels are assigned, re-assigned, and terminated by the Spectrum Access System (SAS) at the end of the term. The PAL will be opened for the third opportunistic licensed-by-rule GAA tier users when unused and further automatically terminated and may not be renewed at the end of its term. PAL licensees report their *PAL Protection Areas* (PPAs) on the basis of actual network deployments., SAS does not authorize other Citizens Broadband radio Service Devices (CBSD) on the same channel in geographic areas and at maximum power levels that would cause aggregate interference within a PPA.

The FCC revisited rules for CBRS in 2016, and introduced the *light-touch leasing process* to enable secondary markets for the spectrum use rights held by PAL licensees [11]. Under the framework, no FCC oversight is required for partitioning and disaggregation of PAL licenses. PAL licensees are free to lease any portion of their spectrum or license outside of their PPA. The PPA can be self-reported by the PAL owner or calculated by the SAS. The PAL radio frequency channel can be re-allocated beyond the PPA, but within the census tract. Introduced low additional administrative burden with a minimum availability of 80 MHz GAA spectrum in each license area will provide the

increased flexibility to serve targeted quantities of spectrum or services to geographic areas. Furthermore, the FCC will permit stand-alone or an SAS-managed spectrum exchange and let market forces determine the role of the SAS value added services.

Berry et al. [1] state that the current secondary spectrum exchange is inefficient because of regulation and transaction costs. There is a need for a more systematic method of allocation, where the process is highly automated to reduce delays, search costs, and transaction costs. This can be achieved with a marketplace that helps to automate many labor intensive and time-consuming parts of the exchange. Tonmukayakul and Weiss [9] use Agent-based Computational Economics (ACE) to study when a secondary market is a viable option i.e., when the license holders are willing to supply licenses and when the secondary users are willing to buy them. The paper concludes that there is a demand for secondary use licenses when buyers find exclusive licenses too expensive or when the unlicensed spectrum is crowded. These conditions are likely to happen in the case of local networks. According to Peha and Panichpapiboon [12], it is profitable for the seller to share spectrum access even if the price is quite low. If the spectrum is unused, the license holders have incentives to sell or lease the license to gain extra revenue and to cover the costs of holding the license. If the transaction is done through an efficient marketplace, the sellers are able to lease or sell even very small licenses with profit.

## 3 Spectrum Broker Service Concept

To increase the efficiency and to make the process more dynamic, the service automates many labour-intensive processes. For example, it generates the contract between the buyer and the seller automatically. It stores the required documentation like CE (Conformité Européenne) certificates and regulator licenses. It also checks that the sale complies with all regulatory rules and possible standards requirements, e.g. regarding to power density and installation parameters. By predicting the aggregated field strengths, the service checks and avoids the harmful interference impact of the buyer network on other licensed radio users in geographic, frequency, and time domains. The service may also visualize the protection and exclusion zones and the respective coverage area of the new license. The estimation of interference protection may include both computed and measured data. Spectrum sales require that documentation concerning the sale is filed to the regulatory authorities. To make the process dynamic, the service creates these documents automatically. The marketplace can also be connected to Enterprise Resource Planning (ERP) software to increase efficiency of accounting. The spectrum broker service is an essential tool in offering Spectrum as a Service (SaaS). The marketplace could offer various additional services to improve the exchange process. It could provide consulting about the pricing, legal processes, or technology. It could also provide advanced information such as sales and sourcing analytics to sellers and buyers, respectively. The marketplace could also include financing services and it could host advertisements and premium listings.

The user interface and the service backend have to be customizable so that they can facilitate the needs of the market for radio spectrum resources. They should allow both selling and leasing as well as allow pricing that is determined flexibly by the pricing

formula. Additionally, there has to be a possibility to integrate a map function to the platform. An open source software platform for a marketplace like Cocorico [13], Sharetribe [14], or Spree [15] could form the basis for an early implementation of the service.

**Listing**

License holders have two options to list their licenses on the marketplace. If they choose to list them automatically, the system determines the base price of the license according to an automated process explained in the valuation section. This allows the license holders to list large amounts of micro licenses conveniently. Alternatively, license holders can list micro licenses manually, one area at a time, allowing them to make a more detailed listing and use a more elaborate pricing method.

Sellers can determine whether they want to lease or sell the license. Both leasing and selling are subject to the legal regulative status of the radio licenses in the particular jurisdiction, and specific radio license terms. It is possible to offer an exclusive license, where only the buyer has access to the spectrum, or a shared license, where many users use the license simultaneously. In the case of a lease, the seller can assume a spectrum manager role where it is responsible of ensuring compliance with terms, regulations, and reporting duties. The exchange can also be a de facto transfer, where all the rights and responsibilities are transferred to the buyer. It should be noted, that the parties must agree who pays the frequency fee.

The marketplace offers analytics tools to sellers to help them monitor the sales. Additionally, it offers an availability management system that helps sellers to manage their available and reserved licenses. An illustration of user interface for listing can be found in Fig. 1.

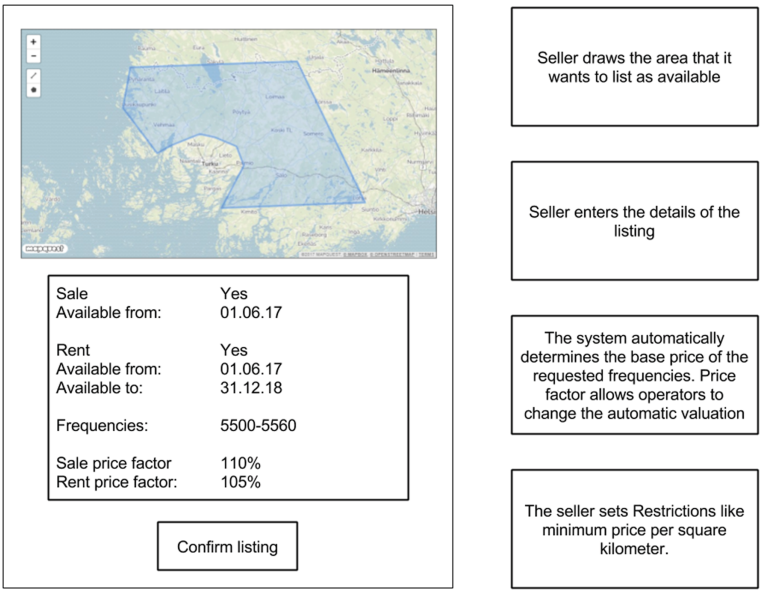


**Fig. 1.** User interface for listing spectrum resources

**Buying and leasing**

The marketplace enables the buyers or leasers to search for license holders and select custom coverage areas. The buyer enters information about planned use, which can be used by the seller to estimate the value of the spectrum use, cost for the frequency fee, and potential for harmful interference. A detailed search engine helps the buyers to find all potential listings. It can automatically combine or divide licenses even from different sellers so that the license matches the needs of the buyer. If the seller uses the automated pricing method or has individually priced the license in question, the service shows the prices immediately and thus allows competitive tendering between different license holders. If there is no available price for the searched license, buyer can ask for a quote from the seller. The buyer has the option to either lease or buy the license. An example of a user interface for searching spectrum resources and the search results can be found in Figs. 2 and 3, respectively.

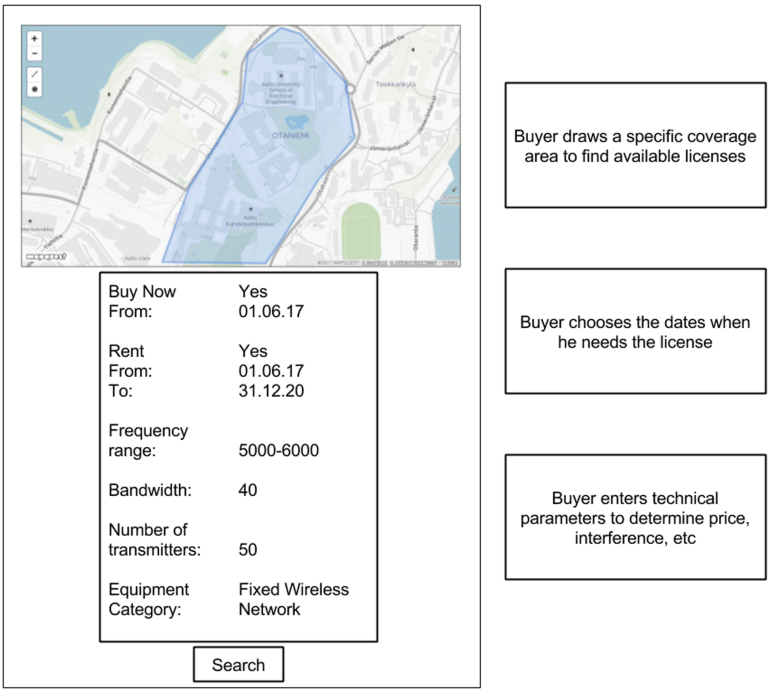


**Fig. 2.** User interface for searching spectrum resources

Real-time markets are mainly proposed to maximize the spectrum utilization during short term changes in the spectrum demand. For example, an operator might lease more capacity during peak hours through the market. However, our proposed market is mainly meant to allocate spectrum to projects and events which are planned in advance or which require a long term license. Because of this, a non-real-time market is sufficient.

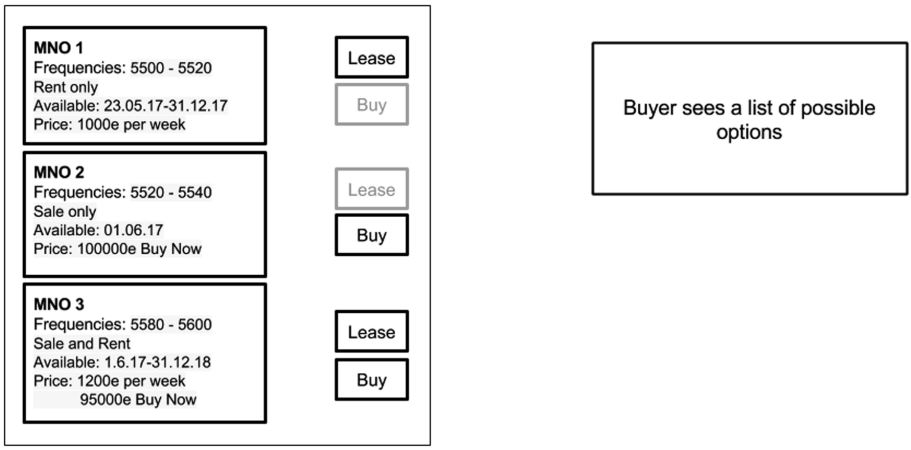


**Fig. 3.** Results from spectrum search

The marketplace acts as an independent third-party broker in the process. There are different possibilities how the marketplace generates revenue. It could take commission from successful transactions. It could charge monthly fees or fees from making listings. The fees from using the basic services of the marketplace should not be too high to drive away the potential buyers or sellers. Fees from the above-mentioned additional services would generate revenue without raising the costs of basic transactions.

## 4 Automatic Spectrum Valuation

In the current proposals of secondary markets, the valuation of the licenses is mainly done by auctions. However, Tonmukayakul and Weiss [9] state that auctions work only when the licenses are liquid, i.e. when there are enough buyers and sellers. In many cases, there are only one or a small number of buyers in the context of licenses for local networks and micro operators. For example, in a case where a factory wants to deploy a local network to its own property, there are no other buyers because the property is only used by the factory.

This paper introduces a new automatic valuation method for these relatively illiquid licenses. The method is based on factors such as availability, usability, and the number of frequency bands in the license. This kind of automated pricing allows license holders to list large areas to the marketplace conveniently. The automatic valuation of a base price can for example be done by using the formula that Finnish Communications Regulatory Authority (FICORA) uses to determine frequency fees [16], see Fig. 4. This formula takes into account the frequency band, population density, number of transmitters, relative bandwidth and used radio equipment. This base price is used to determine the leasing and selling prices in the proposed spectrum broker service.

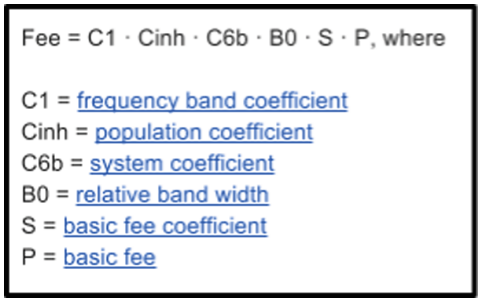


**Fig. 4.** FICORA's formula for computing spectrum resource fee [16]

The buyer's input parameters, like the type of equipment, are used to calculate coefficients such as the basic fee coefficient. The system automatically calculates a part of the factors like the number of inhabitants in the area. This is done by using the selected area and population density data. The license holders can choose to charge a premium on top of the base price. The license holders can further set a minimum price based on area to make sure that the price is high enough for the transaction to be profitable.

Alden [17] analyses many factors that affect the valuation of the spectrum. The paper concludes that the process is complex and often very unique. Because of this, the automated valuation method cannot be applied in every situation. It does not work well in situations where the true valuation is not driven by technical factors such as number of transmitters in use. It is hard if not impossible to automatically evaluate the fair price of the spectrum if the true value is driven by factors such as speculation about future benefits and motives to limit competition. This kind of scenarios are likely to happen for example in campuses and cities. Because of this, the pricing method requires further consideration and can only be used only in limited situations. Alden [17] classifies two different methods for valuing spectrum: direct and indirect method. He states that indirect method, such as benchmarking, is often not viable because comparable cases might not exist. This is especially true in these illiquid micro licenses. Direct method considers opportunity costs and potential revenues. Opportunity costs can be evaluated by determining the costs or profits of the alternative options that the buyer and seller have. These include for example the cost of alternative license that the buyer could use. Potential revenues include for example calculating the net present value of the revenues that the buyer will generate with the license. These kinds of methods might lead to accurate estimates but they are very labour intensive and time consuming. Because of this, these methods most likely cannot be used when determining the price of micro licenses. Using the above-mentioned formula offers an automated and efficient approach to valuation that could be accurate enough for the purposes of illiquid micro license exchange.

Here we consider how the formula recognises the main factors that affect the value of the license according to Alden. Intrinsic factors, such as the unequal capabilities of different frequencies can automatically be taken into account and they are recognised in the pricing method of the FICORA. Namely, frequency band and relative band width coefficients measure these properties.

Some extrinsic factors are also recognised in the pricing method. These include physical characteristics like geography and some socio-economic characteristics such as the number of users in the area. This is mainly recognised in the population coefficient. If the marketplace operates in a specific regulatory environment, extrinsic factors such as market specific regulations are most likely constant and thus they can be recognised as well.

However, some extrinsic factors are hard to calculate automatically. These include, for example, the economic benefit that companies get from using the spectrum. Furthermore, it is not straightforward to evaluate the competitive environment of the specific location. Locations where there are many competitors or just a few dominating ones are not attractive locations for new investments. Furthermore, selling licenses to competitors increases competition in the market and this might generate negative effects for the seller. It is better for the seller to price the licenses manually in situations where this kind of problems arise.

## 5 Conclusions

To enable the efficient employment of local networks and allocation of priority access licenses, a marketplace for illiquid micro licenses is needed. The proposed, non-real-time secondary market is a solution for this challenge. It lowers the transaction costs and inconvenience in the spectrum exchange. Thus, it allows small scale sales that would not be profitable with current transaction costs.

The paper introduces a new automatic method for the valuation of micro licenses. It is based on the frequency fee formula used by the Finnish Communications Regulatory Authority. The method allows license holders to list illiquid micro licenses efficiently. Additionally, it allows buyers to search specific licenses and get the price quotes immediately.

We list a number of features that the proposed system has. To increase efficiency, the marketplace automates labour-intensive processes by filing regulatory documents and checking compliance with the law. Additional services, such as analytics tools and consulting could provide additional value for both the buyer and the seller. The paper shows how the marketplace could be developed by providing examples of the interfaces for both the buyer and the seller. We conclude that an existing open-source platform could be used in the development of the platform. The revenue section shows that there are different business models that could be used to generate revenue without raising the prices too high for the buyers or the sellers.

Future work could consider applying the CBRS brokering concept in to European Licensed Shared Access spectrum sharing concepts evolving from static uses case to more dynamic concept [18]. Finally, the successful deployment of the spectrum trading and leasing framework calls for a collaborative effort from the government, industry, and academia to build dynamic capabilities and technology enablers needed to incubate and accelerate the development. One potential joint topic to study is the utilization of blockchain technology to reduce transaction costs through automatization of business-to-business complex multi-step workflows in contracting and data exchange, while transforming spectrum regulation from administrative to more dynamic market based approach.

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