Location Dependent Spectrum Valuation of Private LTE and 5G Networks in Europe

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Abstract. Emerging private LTE and 5G services and applications have created need for local radio spectrum licensing. The existing pricing models for licenses do not work well in this context. This paper introduces three new location dependent valuation methods that aim to produce more accurate pricing for local licenses. We use FICORA Frequency Fee as our base-case general spectrum valuation model, and we replace the population density based location coefficient with proxies such as employee density, value added per employee, and rent prices. By comparing the differences in the prices yielded by the models, we show that the new models can in some cases identify high demand areas like hospitals and industrial districts better than the original population density based model. Additionally, we conclude that the original population density based model and the new employee density based model could be used together to capture both the consumer and the industrial spectrum demand simultaneously.

Keywords: Private LTE · 5G · Spectrum pricing · Valuation

1 Introduction

1.1 Motivation

Private LTE and 5G networks serve enterprise business, government or education using mobile network technology. The studied mobile networks operate in the radio spectrum bands, which are defined by 3GPP in specification TS 36.101 (2018b). The value of the mobile spectrum for private LTE and 5G networks is dependent on multiple factors, including the bandwidth, duration, area, and location. In this study, the specific interest is in the location of the network area. For services targeted to consumers, the valuation follows the population density, but as no one lives in factories, ports, or in shopping malls, other location proxies should be found for spectrum valuation of private LTE and 5G networks.

Mobile Network Operators (MNOs) have spent billions on gaining exclusive access to spectrum assets and deploying network infrastructure needed to meet current and future consumer demand. LTE evolution and future 5G networks target location specific solutions to meet stringent wireless connectivity needs of distinct vertical use

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cases in the capacity bands. The 5G technologies bring drastic changes to how mobile spectrum is used (5 GPPP, 2016). A significant driver for this is the change in the demand for the licenses of mobile spectrum. During LTE era, the demand has mainly consisted of Mobile Network Operators, which provide Mobile Broadband (MBB) services. However, the potential user-base of 5G is much more diverse. For example, 5G serves the specific communication needs of industries like manufacturing, logistics, and education (Cave and Nicholls, 2017).

The industry and site specific networks require local, private network deployments in contrast to the nation-wide public networks of MNOs. Because of this, there is also a need for a change in the supply side. The recently proposed micro licensing model (Matinmikko, et al. 2017a and 2017b, private LTE and 5G (Ferrus and Sallent, 2014), and network slicing (Alliance, 2016) are concepts for creating customized mobile communications services. Of these methods, micro licensing and private LTE and 5G allow the transaction of spectrum rights in a dynamic way that caters the needs of different user types. In practice, the allocation could be done through a marketplace that works as a centralised, efficient secondary market of private LTE and 5G licenses (Kokkinen et al., 2017) or network slicing (Lemstra, 2018). Cramton and Doyle (2015) state that an open access market for spectrum would increase competition and make the process more efficient, transparent, fair, and simple.

The possibility to deploy private LTE and 5G networks is highly dependent on the spectrum availability. The spectrum could become available through local licenses in the mobile spectrum bands or by allowing unlicensed access to 5G bands (European Commission, 2017). Furthermore, all commercial 5G licenses are advised to be subject to trading or leasing (European Commission, 2018). The novel regulatory approaches include locally licensed mobile spectrum (The Federal Network Agency Germany, 2018; The Swedish Post and Telecom Authority, 2018; Radiocommunications Agency Netherlands, 2018; Ofcom, 2018) wholesale spectrum provisioning, and the secondary market of spectrum. Especially, the 2.3 GHz, 3.5 GHz, and 24 GHz frequency bands are likely to require different approaches to authorization, as they are expected to be the enablers for private LTE and 5G services and applications. The regulators foresee the need for more flexibility in 5G spectrum authorization approaches including the commons approach (general authorization, unlicensed), licensed shared use between different users, geographical sharing, or dynamic spectrum sharing in time, frequency, and location (European Commission, 2018). Sharing-based spectrum management approaches facilitate more efficient spectrum use by allowing two or more radio systems to operate in the same frequency band (Beltran, 2017). Prominent sharing concepts under standardization and trials are the European Licensed Shared Access (LSA) (ECC, 2014), the US based Citizens Broadband Radio Service (CBRS) (FCC, 2016), and the unlicensed LTE technologies: LAA (3 GPP, 2015), LTE-U (LTE-U Forum, 2016), and MulteFire (MulteFire, 2016). 5G convergence with IEEE family of technologies using unlicensed spectrum particularly indoors and dense urban area introduce new opportunities for the co-existence of the 3GPP and the IEEE Wi-Fi ecosystems (Abinader et al., 2014). The 3GPP study item “Study on New Radio (NR) based Access to Unlicensed Spectrum” determines a global solution for NR-based access to unlicensed spectrum (3 GPP, 2018a).

Spectrum management aims at effectiveness by allocating spectrum to the right use, and efficiency by assigning to those what value it the most (Beltran, 2017). Regulators aim at making the best value of spectrum in their decisions, but assessing the value of spectrum is a complex process with multiple perspectives (Bazelon and McHenry, 2013; Mölleryd et al. 2012; ITU-R, 2012). Different wireless services, such as mobile broadband (MBB) communications, Private Mobile Radio (PMR), broadcast, and military use, have different basis for their value due to their distinct business models, technologies, and role in society. Ultimately, the spectrum management decisions are about maximizing the value of spectrum, its efficient utilization, and its benefits to society (Beltran, 2017).

The mobile communication market has traditionally been centered around a small number of MNOs that have been granted long-term exclusive spectrum licenses, most recently through auctions with high up-front payments (Cramton, 2013). While auctions have resulted significant income for the governments in many countries, their impact on society goes beyond auction revenues and has turned out to be a complicated topic to analyze (Cramton, 2013; Hazlett and Muños, 2009; Cave and Nicholls, 2017; Klemperer, 2002). For example, competition, which will ultimately lead to greater innovation and better and cheaper services, will likely generate greater governmental revenues in the long term compared to the sole auction revenues (Cramton, 2013). LTE evolution and future 5G networks are expected to change the mobile communication market structure and be increasingly locally deployed by new entrant stakeholders. Facility owners' role as a local operator serving MNOs' customers is highlighted by Zander (2017) and Ahmed, Markendahl and Ghanbari (2013) as a feasible solution for the deployment of building specific ultra-dense networks. Furthermore, local high-quality 5G wireless networks are gaining increasing attention as the solution to deliver guaranteed quality of service, particularly concerning the low latency requirements, in various use cases of vertical sectors and enterprises (Guirao et al., 2017). Private mobile communication networks as stand-alone solutions or collaboratively serving MNOs' customers are particularly envisaged to operate in shared spectrum bands (ETSI, 2018). Spectrum options for local indoor network deployments by local operators were assessed by Ahmed, Markendahl and Ghanbari (2013) for different spectrum allocation options where the local operators were either collaborating closely with the MNOs or deploying their own independent networks.

1.2 Contribution

In Finland since 2009, the spectrum price of the mobile spectrum bands consists of auction price and yearly frequency fee, which is called FICORA frequency fee in this paper (Note that Finnish Communications Regulatory Authority merged with the Finnish Transport Agency, and as of 1.1.2019, the organisation is called TRAFICOM). In this paper, we use FICORA frequency fee with the modification that the population coefficient is replaced with employee density and with employee density factored with the industry specific value of an employee in the employee-dense areas. The final value of the spectrum is the higher one of FICORA frequency fee and our employment based FICORA frequency fee.

The allocation of local licenses raises an interesting question about how they should be valuated. A marketplace requires a cost-effective and accurate method for valuating the licenses. Traditionally, the mobile spectrum licenses have been sold in large nation-wide bundles to (MNOs) through auctions. There has been less research on how the value of the licenses is distributed on a local level. The demand and value of licenses can drastically change between different locations. Moreover, the type of use also affects the price. While the current mobile licenses are primarily used for Mobile Broadband, 5G technology can be used for diverse use cases, including private networks. These should be taken into consideration in the valuation of the licenses.

There are several challenges related to spectrum market, one of which is the valuation of the licenses. In this paper, we research different methods of valuation and compare the pricing results that the methods yield. The aim of this paper is to develop a location dependent valuation method of private LTE and 5G spectrum for industrial users. This study contributes to the literature the need to extend the private LTE and 5G spectrum valuation methods with an employment based, geographic distribution of the spectrum price. The reminder of this paper will continue as follows: Spectrum valuation for private LTE and 5G is introduced in Sect. 2, Sect. 3 discusses the proposed valuation model and data to validate the model, the results are described in Sect. 4, and the conclusions can be found in Sect. 5.

2 Spectrum Valuation for Private LTE and 5G

2.1 Conventional Valuation Methods

The commercial value is the price of a private LTE and 5G radio spectrum license should it be for sale. We focus on the commercial value of local licenses for private LTE and 5G networks. The value is determined by the expected future cash flows that the license generates to its holder. These cash flows are generated through additional increases in revenues or reductions in costs. The license can for example be used to offer a new product to increase revenues, or to implement a new manufacturing method to reduce costs. Licenses can also be used defensively to limit competition. By blocking competition, the license holders can use their improved market power to increase cash flows. Additionally, Marks et al. (2009) note that radio spectrum licenses hold a significant option value.

The valuation of licenses should be based on the above mentioned underlying economic factors. Conventionally, the price of a mobile license is determined through auctions. Given a sufficient number of buyers, auctions result in relatively accurate pricing as the buyers can use sophisticated, context specific financial models to estimate the economic factors. However, due to the small value and illiquidity of licenses for private LTE and 5G networks, auctions are often not a viable method of pricing. One local license can for example only cover the area of a single factory or port, which means that the license has only one potential buyer. Small number of buyers makes auctions inefficient (Tonmukayakul and Weiss, 2008). Additionally, the context specific financial models used by the buyers in auctions, as well as in the bidding process, can be very resource intensive. These costs can be relatively large compared to the commercial value generated by the trade of a local license for private LTE and 5G networks.

Benchmarking is another market-based approach for pricing radio spectrum licenses. Benchmarking would solve the problem of high valuation costs as it can gather large amounts of market information cost effectively. However, the markets for local 5G licenses do not currently exist in large extent, so due to the immaturity of the market, benchmarking is not viable in the early stages of 5G. Furthermore, even if the market was more mature, it could prove to be very difficult to find sufficiently similar comparables for the licenses as the value of the license is determined by many context specific factors. Thus, if benchmarking was to be used, it should be adjusted to account for these factors.

2.2 General Spectrum Valuation Model

As the market-based valuation methods accommodate the market for local 5G licenses poorly, we seek to find a general valuation model that uses the characteristics of the spectrum to determine a price for the license. In this paper we study whether some set of intrinsic characteristics can be used as proxies to estimate the commercial value with a sufficient accuracy.

Typically, general spectrum valuation models used by regulators consist of the following variables: the opportunity cost for a given band and location, the amount of spectrum used, the type of service, the frequency band, and the location (Marks et al., 2009). Kokkinen et al. (2018) used the frequency fee developed by the Finnish Communications Regulatory Authority to price spectrum licenses. The Table 1 shows that the formula used by FICORA (Finnish Ministry of Transport and Communications, 2017) fits well to the general model. Both models measure similar intrinsic commercial value drivers.

Table 1. Fitting FICORA frequency fee to the general model.

General model	FICORA frequency fee
Opportunity cost for a given band and location	P basic fee
Amount of spectrum used	B0 relative bandwidth
Type of service provided	S basic fee coefficient (Type of radio equipment used) C6b system coefficient (Scaled number of transmitters used)
Frequency band	C1 frequency band coefficient
Location	Cinh population coefficient

FICORA fee uses population density as a measure for location value. However, as noted by Kokkinen et al. (2018), population density might not accurately estimate the commercial value of local 5G licenses as these are often used in industrial districts and sites such as factories and ports. These locations typically have a low population density even though the willingness to pay and demand for licenses might be high. Thus, using population density might underestimate the value of local 5G licenses. In this paper, we present alternative proxy measures to estimate the location value for local 5G licenses.

We sought to find alternative measures that are based on globally available open data. We research potential measures that would be based on proxies such as land prices, density of business activity, and value added locally. However, we selected employee density and commercial property rental prices as proxies for location value because the availability of data and our hypothesis that including either one or both of these measures in the valuation formula would improve its accuracy in valuation of local 5G licenses.

3 Valuation Model and Data

3.1 Approach

We use the FICORA Frequency Fee formula as our base case model. The formula uses population density as a measure for location value. In this section, we substitute the population density with other measures, namely employee density, adjusted employee density, and commercial property rental prices. The total value of the spectrum is obtained using the FICORA Frequency Fee, and it is then redistributed using other valuation methods. Thus, this paper mainly studies the relative prices yielded by different valuation methods. The absolute prices of licenses would change if other methods such as benchmarking would be used to calculate the total base value of the spectrum. The total value of licenses is the same in all models. However, the way in which this total value is distributed to different locations changes.

If a combination of two methods is used, such as the max function of two valuations, the total value for the spectrum will be higher than the total base value of the spectrum. The base value reflects the spectrum value when it is used only for consumer services.

3.2 Data

We use population density, employee density, and area data from Official Statistics of Finland (2018a). The database includes statistics for all 3030 postcode areas and it uses 2018 postal area classification. The database includes the most recent population and employee data, from 2016 and 2015 respectively. The value added per employee by industry data used for Adjusted Employee Based valuation is from Official Statistics of Finland (2018b). The commercial property rental prices are obtained from City of Helsinki (2018). The rental price data used a different area classification so the data was matched to postcode areas as closely as possible.

3.3 Base Case: FICORA Frequency Fee Using Population Density

FICORA Frequency Fee formula is currently used in Finland to determine the annual frequency fee for all spectrum licenses in Finland. It is based on factors such as availability, usability, and number of frequencies in the license (Finnish Ministry of

Transport and Communications, 2017). The formula fits well to the general model as seen from Table 1.

$$FICORA\ Frequency\ Fee = C_1 * C_{inh} * C_{6b} * B_0 * S * P \tag{1}$$

Table 2. FICORA frequency fee coefficients.

Coefficient name	Coefficient	Value
Frequency band coefficient	C_1	0.4
Population coefficient	C_{inh}	Variable
System coefficient	C_{6b}	1
Relative bandwidth	B_0	2000
Basic fee coefficient	S	0.018
Basic fee	P	1295.5 €

The constant values on Table 2 are set by FICORA (Finnish Ministry of Transport and Communications, 2017) for a 1-year public mobile network license with a bandwidth of 10 MHz and area of 1 km in the 3.5 GHz frequency band. The values are also the same as used in Kokkinen et al. (2018). The population coefficient is calculated for each postal code using the Eq. (2).

$$C_{inh} = \frac{POP_{PC}}{POP_{FIN}} * \frac{1\,km}{A_{PC}} \tag{2}$$

Where POP_{PC} is the population of the postal code area, POP_{FIN} the total population of Finland, $1\,km$ the constant area of the license, and A_{PC} the area of the postcode.

3.4 Location Coefficient Variation: Employee Density

The Employee Density formula is the same as FICORA formula, with the exception that employee density data is used instead of population density data. The Employee Coefficient Cemp is obtained by dividing the number of employees working in the license area by the number of employees in Finland.

$$Employee\ Density\ Valuation = C_1 * C_{emp} * C_{6b} * B_0 * S * P \tag{3}$$

$$C_{emp} = \frac{EMP_{PC}}{EMP_{FIN}} * \frac{1\,km}{A_{PC}} \tag{4}$$

Where EMP_{PC} is the number of employees working in the postal code area, EMP_{FIN} the total number of employees in Finland, $1\,km$ the constant area of the license, and A_{PC} the area of the postcode.

3.5 Location Coefficient Variation: Adjusted Employee Density

The Adjusted Employee Density formula is the same as the Employee Density formula, with the exception that employees from different industries different weights. The weights are based on the industry value added per employee. The rationale behind this is that the number of employees might not be comparable between different industries. For example, some industries are more automated than others. By using weights, locations where employees work in high value adding industries are more expensive

Each industry's employee weights (EW) are calculated by dividing the average employee value added in that industry by average employee value added in Finland (Eq. 7). If there was no data on a particular industry's value added, the average for whole Finland (weight of 1) was used for that industry.

$$Adjusted\,Employee\,Density\,Valuation = C_1 * C_{emp,adj} * C_{6b} * B_0 * S * P \tag{5}$$

$$C_{emp,adj} = \frac{\sum_i EW_i * EMP_{PC,i}}{EMP_{FIN}} * \frac{1\,km}{A_{PC}} \tag{6}$$

$$Employee\,Weight(EW_i) = \frac{Average\,Employee\,Value\,Added\,in\,Industry\,i}{Average\,Employee\,Value\,Added\,in\,Finland} \tag{7}$$

3.6 Location Coefficient Variation: Rent Based

The Rent Based valuation uses commercial office rental prices per square meter to calculate the location value. For this research, data was available for selected areas in the Helsinki region. We calculated an average price for a 1-year public mobile network license with bandwidth of 10 MHz and area of 1 km in the 3.5 GHz Frequency Band in the selected areas using the Employee-Based Valuation. The average price was calculated using employee-weighted average, i.e. the relative number of employees in the area was used as the weight. We then used relative rent prices as a coefficient to evaluate licenses in different areas.

$$Rent\,Based\,Valuation = License\,Value * \frac{Rent_{PC}}{Rent_{ALL}} \tag{8}$$

Where License Value is the employee-weighted average of a license in the selected areas according to the Employee-Based Valuation. $Rent_{PC}$ is the average rent in the postcode area, and $Rent_{ALL}$ is the employee-weighted average of rent in the selected areas.

The data used is from selected areas from the Helsinki region and it uses office rental prices. Data from wider area using industrial rental prices exists but was not available for this research (KTI Property Information Ltd. 2018). This more extensive data could be used to increase the accuracy of this method.

4 Results

All prices in this paper have been calculated for a 1-year license with bandwidth of 10 MHz in the 3.5 GHz frequency band. In the Table 3 and Fig. 1, we show descriptive statistics of prices obtained by different valuation methods for all postcode areas and selected areas in the Helsinki region. The rent based valuation is calculated only for the selected areas in the Helsinki region. The pricing results including the rent based method are shown in Table 4 and Fig. 3.

4.1 Comparison of FICORA, Employee Based, and Adjusted Employee Based Prices

In this section, we have selected 100 postcode areas that have the highest valuation based on the Employee Based method as these types of areas are most relevant for local 5G licenses.

Table 3. Comparison of prices yielded by different valuation methods. The 100 highest priced areas using the employee density method are included.

	Min (€)	Max (€)	Mean (€)	Employee-weighted mean (€)	Median (€)
FICORA	0.00	73.39	11.82	14.10	9.17
Employee based	10.30	364.09	48.07	63.58	24.21
Adjusted employee Based	10.20	366.34	48.36	64.86	24.73

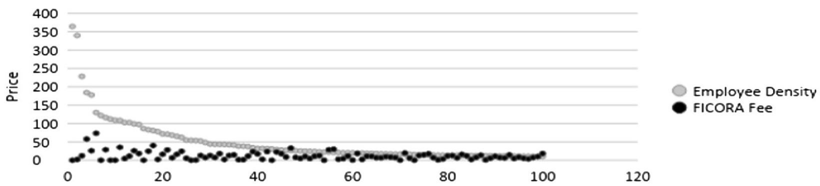

Fig. 1. Comparison of prices yielded by the employee density and the FICORA Fee method. The 100 highest priced areas using the employee density method are included.

The Employee Based valuation methods generate significantly higher values than the FICORA Frequency Fee for certain areas. This is explained by the fact that employment is concentrated more than residency. Areas such as commercial and industrial districts have a very high employee density compared to the population density of even the most populated residential areas. Conversely, as residency is more spread out, the population based prices of for example rural and residential areas are typically higher than employee based. Interestingly, there is a group of postcode areas that have no residents but a high employee density. Examples of these locations are the hospital area of Joensuu, the office park of Ilmala, Turku University of Applied Sciences, and industrial district of Martinlaakso (Fig. 2).

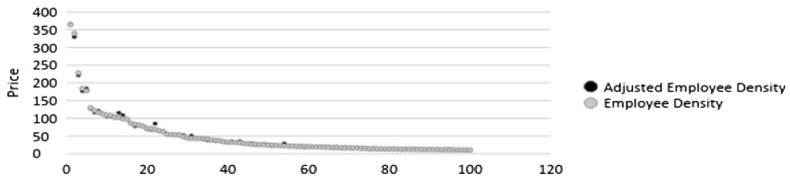

Fig. 2. Comparison of prices yielded by the employee density and the adjusted employee density method. The 100 highest priced areas using the employee density method are included.

Employee Density and Adjusted Employee Density based valuation methods yield very similar prices. However, differences occur in areas where the employees work dominantly in industries that have either relatively high or low value added per employee. Examples of locations where the Adjusted Employee Density yields higher results are postcode areas with large powerplants (Olkiluoto, Tahkoluoto), some industrial districts (Martinlaakso industrial area), and university campuses (Otaniemi).

4.2 Comparison of Prices, Including the Rent Based Method

In this section, we show the prices for selected areas in the Helsinki Region. The reason for selecting these areas was the availability of detailed commercial rent prices.

Table 4. Comparison of prices yielded by different valuation methods, including the rent based method. Selected areas in the Helsinki Region are included.

	Min (€)	Max (€)	Mean (€)	Employee-weighted mean (€)	Median (€)
FICORA	2.71	73.39	16.77	18.00	11.18
Emp. based	3.87	228.05	54.50	90.57	25.75
Adj. emp. based	3.86	221.47	56.33	94.66	24.54
Rent based	56.84	126.34	81.14	90.57	76.43

Using the Rent Based valuation, the license prices are significantly more evenly distributed than using the other methods. Because population density and employee density can vary significantly between areas, the prices based on these methods also vary significantly and they can even be close to zero. However, office rents do not have this same characteristic and thus license prices based on rents are distributed more evenly.

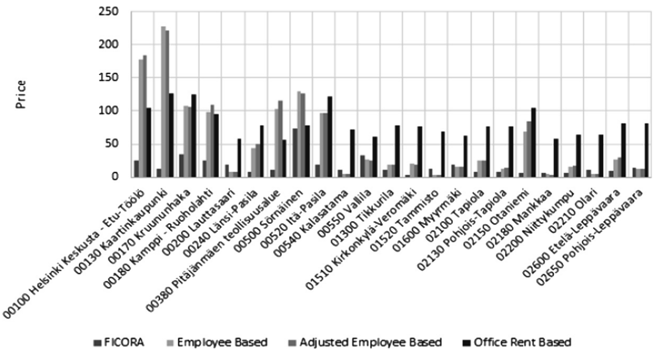

Fig. 3. Comparison of prices yielded by different valuation methods, including the rent based method. Selected areas in the Helsinki Region are included.

5 Conclusion

As the 5G utilising technology and use cases for local licenses develop, there is a growing need to evaluate local 5G licenses. In the introduction, we presented arguments why conventional valuation methods, namely auctions and benchmarking might not work in this context. Additionally, we argued that existing population density based general valuation models might not accurately proxy the underlying drivers of location value in commercial local licenses. In this paper, we proposed two alternative proxies for location value drivers: employee density and commercial rental prices.

As seen from the results, the four valuation methods used distribute the total value of spectrum differently. The FICORA Frequency Fee is based on population density, and it is a good measure of location value for mobile broadband, where the customers are mainly private consumers. However, we can see from the results that this valuation method is not always sufficiently accurate in the context of commercial local licenses. There exist many postcode areas that have a population of zero but that have potentially high demand for local licenses. These areas include, for example, industrial districts and hospital areas. Using the Frequency Fee based valuation, the prices for licenses in these areas are very low, which does not accurately reflect reality. This problem would be even more noticeable if we were to use areas smaller than postcode areas.

Kokkinen et al. (2018) summarises this problem with a sentence: “No one lives in factories or ports.” We might add: “But many work there”. The two proposed employee density based methods are able to identify areas with low population density but high potential demand for spectrum. The methods also show that employment is more concentrated than residency. Companies tend to group up in small areas, which locally increases the demand for spectrum. This is reflected in the prices of licenses: the highest prices using employee density are significantly higher than the ones the population density based method yields. Conversely, prices for low demand areas are lower with employee density valuation.

In the basic Employee Density valuation, all employees drive the spectrum value equally. However, this might not reflect the reality as different types of employees, companies, and industries have different demand and willingness to pay for spectrum. Because of this we introduced the Adjusted Employee Density valuation, where employees from different industries were weighted based on their average value added. This method distinguished for example that the employees of energy companies such as nuclear plants have a very high value added per employee and thus areas with energy plants were given a higher license price per employee. The industry categories we used were very broad. For example, all manufacturing companies were consolidated in the same category. With more detailed categories, the usability of this method would increase significantly. It could, for example, be very useful to distinguish smart factories as their own category, as these factories typically have a very low ratio of employees to value added. Additionally, value added per employee is not the only, nor necessarily the best way to weight employees. Some industries might have a high value added but no demand for local licenses. Further research on how new 5G technologies will benefit different industries, especially in monetary terms, would improve the pricing of licenses between industries.

Value of Mobile Broadband licenses is very much location dependent. If an area has no users for the service, the price of that local license is close to zero. The value of the license increases in the number of users as the potential revenues also increase. The Employee Density based valuation makes the same assumption on commercial local licenses and it might not always reflect reality. Often a factory makes similar profits no matter if it is surrounded by other businesses or not. A new factory under construction might not have many employees working at the site yet but still its willingness to pay for license can be high. In the light of these arguments, it is possible that the Employee Density based method generates too stark differences between locations.

Because of this, we introduced another proxy for location value, commercial rental prices. Average rents change based on the location, but not as abruptly as employee density. Rent prices do not drop to zero even in very rural areas. As seen from the results, the rent based method yields more -evenly distributed prices than the other methods. Still, it ranks different locations very similarly to the employee based method as the prices generated by these two methods have a strong correlation. Because of the limited availability of data for this research, we used only office rent prices for selected areas in the Helsinki region. There exist more extensive databases, which could be used in further research for more accurate pricing.

The valuation method should enable an allocation where the party with the highest willingness to pay gets the license. To achieve this, a combination of different valuation methods could be used. For example, the license price could be the maximum of the population density based valuation and the employee density based valuation. If the location has a high population density compared to employee density, the most efficient allocation is most likely to use the license for mobile broadband. By using max function, the license will always be sold at the higher price, which in this case incentives mobile broadband use.

Spectrum pricing should follow demand and be based on transparent methods and easily available data. The demand for consumer services such as mobile broadband follows population density but this is not necessarily true for industrial demand. We recommend the use of employee density as a measure for the industrial demand. This can be adjusted to reflect the differences between industries. Optionally, rent based valuation can also be used to price licenses. A combination of these methods, such as the max function of population density and employee density valuation, allows the consideration of both consumer and industrial demand simultaneously. This method will always price the licenses to match the highest willingness to pay.

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