Pricing Private LTE and 5G Radio Licenses on 3.5 GHz

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Abstract. The interest in private LTE and private 5G radio licenses is increasing along the IMT frequency bands, higher frequencies, new spectrum assignments, and demand for wireless industrial communication. This paper studies the private LTE and 5G license pricing using Finland as an example. The methods for pricing are the actual block license-based frequency fee pricing, Administrative Incentive Pricing (AIP), device based Private Mobile Radio pricing, and the device-based pricing of the Netherlands. The study shows that the selection of the pricing mechanism greatly impacts the license prices. Spectrum policy and regulation can be the trigger for novel private network ecosystem creation through creation of simple authorization processes to reduce the cost and minimize the complexity of use of spectrum for private LTE. In particular, provision of clear rules and guidance for spectrum valuation and pricing for the national regulator itself, as well as for the stakeholders wanting to supply and operate private LTE was found essential in reducing the cost and minimizing the complexity of private LTE spectrum use.

Keywords: Mobile communication market · Private networks
Spectrum pricing · Spectrum sharing · Regulation · 5G

1 Introduction

The increase of private LTE and 5G networks stem from the following changes in the society: explosion in number of IMT frequency bands, higher frequency ranges, new types of radio licensing for 3GPP technologies, and demand for wireless industrial communication. The private LTE concept is an enabler for industrial automation and it is realizable now. The roll out of private LTE and future 5G is constrained by an inability to access quality spectrum timely. Authorization of this spectrum is required on a localized basis in contrast to the national and exclusive basis that has applied for mobile network operators providing services to the public to date. The benchmark pricing of private LTE and 5G licenses is challenging, because the prices of nationwide

I. Moerman et al. (Eds.): CROWNCOM 2018, LNICST 261, pp. 133–142, 2019.
https://doi.org/10.1007/978-3-030-05490-8_13

mobile broadband radio licenses for public networks are considered to be very high and the radio licenses for private wireless networks very low.

The Evolved Universal Terrestrial Radio Access (E-UTRA) mobile broadband frequency bands have grown from 17 in 3GPP release 8 in 2007 to 60 in release 15 in 2017 [1, 2]. The difference in the number of frequency bands supported in eNodeBs and User Equipment (UE) globally and the number of frequency bands taken into use in an arbitrary country has grown even faster. It means that there are commercial off-the-shelf mobile devices and networks available for the frequency bands, which are not used by the mobile operator. Some of these bands could be potential for private LTE and 5G networks.

In 3GPP release 8 in 2007, the frequency bands reached at highest 2620 MHz [1], and in 2017 in release 15, the frequency bands went up to 5925 MHz [2]. For future 5G use, European Commission Radio Spectrum Policy Group (RSPG) recommends the 24.25–27.5 GHz as a pioneer band in Europe and considers that the band 40.5–43.5 GHz is a viable option for 5G in the longer term [3]. According to Global System Mobile Association (GSMA), the coverage bands are on the mobile broadband frequency bands 1.4 GHz and below [4]. The higher frequency bands are capacity band and their primary purpose is to provide capacity in densely populated areas. The capacity bands are potential for private LTE and private 5G due to limited coverage of the public mobile operator network and interference of private LTE and 5G networks only on a limited geographic area.

Practically, all deployed mobile broadband networks have block licenses. it means licensing of a block of spectrum on an area-defined basis [5]. The emerging licensing methods include license-exempt [6], Licensed Shared Access (LSA) evolution [7], and Citizen's Broadband Radio Service (CRBS) [8]. Spectrum assignments based on them lack coverage requirements, encourage for small mobile broadband networks, and decrease cost of spectrum access for private LTE and 5G networks. The most common alternative to the block licenses are device licenses. In the case of LTE or 5G networks, the price of the license is based on the number of the eNBs in the license.

The performance dimensions of 5G are: enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC), and Ultra-Reliable and Low Latency Communications (URLLC). They have been developed to support the requirements of vertical industries like factory automation. The main approach to satisfy the different Key Performance Indicators (KPI) of the various performance dimensions by a Mobile Network Operator (MNO) is to deploy network slicing [9]. Alternatively, the vertical industries may operate their 5G network using an own radio license, or a license traded or subleased from a MNO [10]. Key to the success of private network solutions is the ability to access suitable harmonized mobile spectrum in required locations in a timely way and on appropriate terms. This is likely to be challenging given the current approach to assignment of this spectrum, the lack of active secondary spectrum markets, and the very limited use of spectrum sharing in these bands.

The cost of getting and holding a radio license typically consists of a one-time auction price, a recurring frequency fee, or both of them. In Finland, the auction prices are market based and the auction payments go to general public treasury, whereas the frequency fees are used to cover the costs of the National Regulatory Authority (NRA).

As the regulator is a governmental non-profit organization, the frequency fee level is adjusted to the cost of administration, and not market based in 2018. The Finnish Information Society Code [11] added a possibility for Administrative Incentive Pricing (AIP) for the situations that a network license for telecommunications and television operations has been granted free of charge by the Government. The Finnish AIP is applicable in the cases where there is a lot of demand for the licenses and auctions or other market mechanisms have not been used in the spectrum assignment. In addition to AIP or auction, the spectrum holder also has to pay the frequency fee. The frequency fees in the UK, Sweden, Norway, Denmark, Ireland, Czech Republic were studied in [12].

In market economy, the price reflects supply and demand. When there is little liquidity due to limited supply or demand, the auctions do not work and price equilibrium between demand and supply is difficult to quantify [13]. Instead, different valuation methods are required. Valuation methods can be categorized into engineering value [14], Economic value [15], and strategic value [16]. The approaches for radio license pricing include: Direct benchmarking, Adjusted benchmarking, Econometrics, Avoided cost models, Full enterprise valuation, and Iterated cost models [5].

A larger scale of private LTE or private 5G network licensing is expected to begin in the band 3.4–3.8 GHz [17]. The reasons for that are: it has been selected as a 5G pioneer band [18], the LTE bands (42, 43, and 48) have been specified quite recently, and the equipment is appearing on the market. As a capacity band, the mobile operators will not deploy a large coverage network like in the coverage bands. Due to several incumbent governmental and commercial users in the band, it is difficult to clear the whole band for mobile broadband in most countries encouraging to local licensing. Local licensing regulation has been taken into use in the 3.5 GHz band in the Netherlands [19, 20], in Germany [21], and in Ireland [22]. It is about to come out in the US very soon [8] and it is considered e.g. in Finland.

Although, the spectrum decisions will have large impact on societies and key stakeholders' businesses, there is very little prior work on spectrum pricing in the context of private LTE or 5G networks. Therefore, this paper aims to study *how currently used pricing models fit to private LTE and private 5G radio licensing models*. The study calculates a radio license price for small, medium-size, large private LTE networks in various parts of Finland using the Finnish frequency fee, Finnish Private Mobile Radio (PMR) frequency fee, the AIP of the Finnish Information Society Code [11] applied to private LTE, and the Netherlands private LTE pricing [19].

License pricing is one of the tools, which the regulative authorities can use for spectrum management. The single most important target is efficient spectrum management, that leaves freedom for interpretation what efficient means. From the economy of the society perspective, the efficiency could be described as capability to create and provide communication services, the price level of the services, business activity, and employment [23]. More concretely, the spectrum pricing should encourage the license holder to invest in network infrastructure rather than speculate with the value increase of under-utilized spectrum. The pricing should allow the possibility to allocate the spectrum licenses to the user, who can create most value for the society with the spectrum resource. The pricing tools for the regulative authority to achieve efficient spectrum management include: auctions, Administrative Incentive Price (AIP), reselling rights of licenses, and technology and service independence of the licenses [23].

Our assumption is that the market of private LTE licenses, on large, does not have enough demand and supply from multiple stakeholders to make the auctions possible. The auctions are taken into account in this study as benchmark analysis and mapping the respective auction prices from liquid markets to frequency fee-type pricing. AIP pricing is derived from the Finnish AIP pricing of free-granted network licenses for telecommunications and television operations. These are compared to non-market-based frequency fee of block and device frequency licenses.

The rest of the paper is organized as follows. First, an overview of the pricing methods and data is presented. Then, the results of the pricing use cases are presented and discussed, followed by the conclusions in Sect. 4.

2 Pricing Methods and Data

In Finland [24], frequency fee is based on the availability, usability, and the frequency range. The frequency fee is calculated [25].

$$Fee = C_1 C_{inh} C_{6b} B_0 SP, \text{ where,} \tag{1}$$

C_1 is frequency band coefficient, C_{inh} is population coefficient, C_{6b} is system coefficient, B_0 is relative bandwidth, S is basic fee coefficient, and P is basic fee. The used coefficient values can be found in [24], and the numerical values are summarized in Table 1.

Table 1. The frequency fee coefficients for a private LTE or 5G network with a 10 MHz bandwidth in the 3.5 GHz band for one year

Coefficient	Block	Applied AIP	PMR
C_1	0.4	0.4	0.4
C_{inh}	Variable	Variable	0.01
C_{6b}	1	1	Variable
B_0	2000	2000	9.28
S	0.018	0.018	2.1
P	1295.5 €	9300 €	1295.5 €

The population coefficient is C_{inh} is obtained for block licenses by diving the inhabitant number living in the license area by population of Finland. C_{6b} system coefficient for device licenses is 0.25 x device number and the maximum value is 23.75, when there are 100 or more devices in the license. The minimum frequency fee is 18 €. According to the Finnish legislation, the frequency fee for mobile bands is calculated according to block license rules. The other options: applied AIP, PMR, auction and Netherlands pricing are just illustrative methods for comparison. The Netherlands license price is fixed 633 € per base station [19].

The auction price is based on the mean auction price in the 3.4 to 3.8 GHz bands in Slovakia, Romania, Hungary, Montenegro, Ireland, Czech Republic, Australia, UK, and Austria between May 2015 and March 2018. The mean sample value without the reserve prices in these auctions is 0.05 USD/MHz/pop for a 15-year period [26]. The annual amount of the auction price is calculated by multiplying one 15^{th} of the average auction price with population density and the size of the license area.

The data for the study represents a random selection of a 2 km^2, 10 km^2, and 100 km^2 area in Finland. The location probability is weighted according to the population density in the location. This data selection means that each person living in Finland applies for a single private LTE license in their home municipality. The resulted distributions describe the price distribution of those applied private LTE licenses. For device-based license prices, we estimate 0.5 eNBs per km^2 in 2 km^2 area, 0.2 eNBs per km^2 in the 10 km^2 area, and 0.1 eNBs per km^2 in the 100 km^2 area. In all areas, we estimated 10 UEs per eNB. UE frequency fee is applicable only in PMR pricing. Ficora calculates the exact inhabitant number in the license area. In this study, we use the average inhabitant density for each municipality area.

In the data, for each municipality there is the same relative number of LTE private networks as there are inhabitants. In the smallest municipality, there is one reservation. The less populated areas of a municipality even out the most expensive urban areas in the same administrative area. As this method limits the maximum frequency fee price, we divide the largest city Helsinki in 9 different areas. We do not separate the cases where the municipality area is smaller than the license area. Compared to the real Ficora fees, this computation gives a little bit lower maximum fees and the distribution has visible steps representing the largest cities. Whereas the real Ficora fee distribution is smooth. In large areas, the real Ficora fees do not go quite as high as in this study, because there are no 100 km^2 areas with the highest population density.

3 Results

The license prices are calculated for 1 year with 10 MHz bandwidth in the 3.5 GHz mobile band. Three different license area sizes are studied: 2, 10, and 100 km^2 in Finland. The pricing is presented for Finnish block license, applied AIP, device licensing with the Finnish PMR method, device licensing with the method of the Netherlands, and an average European Union auction price on 3.4–3.8 GHz. The minimum, maximum, average, and median of the license prices in different municipalities in Finland are collected in Table 2.

The distributions of license prices covering an area of 2, 10, and 100 km^2 in different municipalities in Finland are presented in Figs. 1, 2, and 3, respectively. As the only difference between the applied AIP frequency fee, applied auction price, and the frequency fee is the basic fee, the form of the curves is similar. The Netherlands private LTE and Finnish PMR methods use device licensing. The price is not dependent on the population density, and they appear as step functions in the CDF graph. The number of base-stations per square kilometer is different in 2, 10, and 100 km^2 license areas. Consequently, the relative position of the step functions differs from the distribution curves in the respective graphs.

Table 2. Basic characterization of the studied license prices

Pricing	Min (€)	Max (€)	Average (€)	Median (€)
FIN Block 2 km^2	18	41	18	18
FIN Block 10 km^2	18	413	18	18
FIN Block 100 km^2	18	4135	97	18
Applied AIP 2 km^2	18	148	18	18
Applied AIP 10 km^2	18	1484	35	18
Applied AIP 100 km^2	18	14844	350	26
FIN PMR 2 km^2	278	278	278	278
FIN PMR 10 km^2	556	556	556	556
FIN PMR 100 km^2	2652	2652	2652	2652
NL 2 km^2	633	633	633	633
NL 10 km^2	1266	1266	1266	1266
NL 100 km^2	2652	2652	2652	2652
AUC 2 km^2	18	164	18	18
AUC 10 km^2	18	1645	39	18
AUC 100 km^2	18	16446	388	29

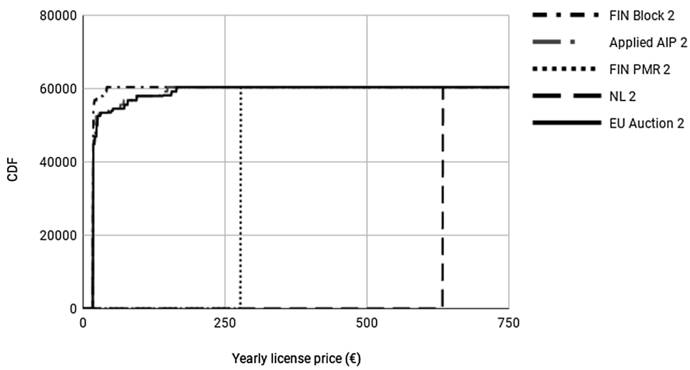

Fig. 1. Cumulative distribution of 2 km^2 license prices with different pricing methods.

The auction derived license pricing is the highest one among the population density depending license cases. The applied AIP price is very close to the auction price. The auction price is the most expensive one especially in the high-density areas. Depending on the device number per square kilometer, the device-based licenses are most expensive in sparsely populated areas and generally lowest cost in the areas of highest population density. The Netherlands device-based license is more expensive that the Finnish device license. The relative difference between Finnish and Dutch device licenses partially depends on the selected number of UEs per eNB. The impact of the number of the UEs becomes smaller in large areas as the PMR cost increases along the device number up to 100 devices.

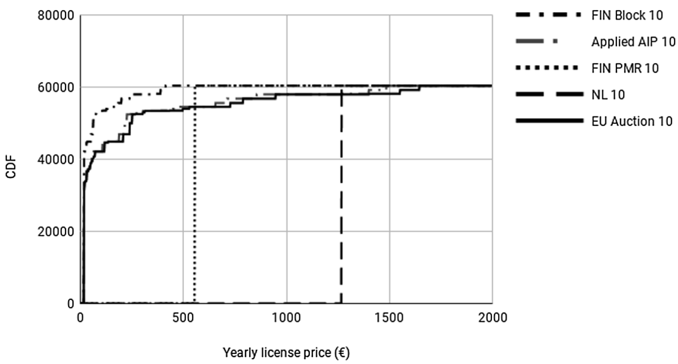

Fig. 2. Cumulative distribution of 10 km^2 license prices with different pricing methods.

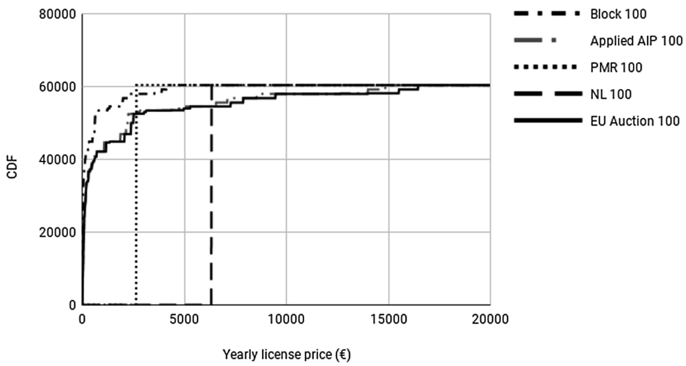

Fig. 3. Cumulative distribution of 100 km^2 license prices with different pricing methods.

4 Conclusions

There is ongoing development of private LTE and 5G network solutions for industrial automation. Timely access to harmonized mobile spectrum in required locations and with appropriate terms is key to the success of private LTE and private 5G solutions that are an enabler to industrial automation. Private LTE networks are, by their very nature, designed to be small-scale, sub-national and sometimes short-term. As a result, any licenses that are only available on national basis, with long license durations, and high upfront investment are not suitable, and are unaffordable for private LTE operators.

In this study, we compare different pricing methods for private LTE networks in the 3.5 GHz band using Finland as an example area. We compare on one hand AIP pricing to non-market priced licenses and on the other hand pricing based on device number to pricing based on population density. The selected cases partially represent the one-time payment (auction) and recurring payment (frequency fee). In many countries, these payment methods are bound to financing the operation of the radio administration.

A common situation is that the recurring frequency fees are used to cover radio administration costs, and the one-time auction payments fill the general government treasury. A mixture of these are AIP fees, which exceed the costs of radio administration, and which can either be dedicated to the communications authorities or grow the government treasury.

Two practical targets set in the introduction were: encouraging investments in the network infrastructure and allowing allocation of spectrum resources to the stakeholders who can create most value with the resource. When device and block licenses are compared, the device licenses decrease the interest to invest in the network infrastructure due to increasing cost, and they encourage to keep spectrum unused because it is possible to hold a lot of spectrum resources with minimal cost. Similarly, one-time payments can be considered as investment instruments by the license holder rather than as a resource to facilitate new business. Recurring payments force the license holder to continuously consider, if the value created with the spectrum resources is high enough to justify holding the license.

The auctions are an obvious tool to allocate spectrum to the stakeholder offering most for the resource on the markets where there are several buyers bidding for the spectrum. Unfortunately, it cannot generally be expected in the case of private LTE networks. An alternative to auctions is to keep frequency fee high enough to be selective in terms of buyers. The level of the frequency fee should in optimal case be derived from the market price for example by benchmarking from auction prices, known acceptable market price, or by deriving it from business models of the buyer. An observation of the relative position of the population density dependent distributions is that for the 3.5 GHz private LTE licenses the applied AIP price and auction benchmark prices are very well in-line.

The price should follow the demand. The areas and frequency ranges, which have a lot of demand should have higher prices than the ones with little demand. Generally, we can assume that the areas with high population density have high demand and the areas with low density have less demand. In the results section, we show that fixed device pricing does not follow the population density. It creates an obstacle to utilize the resource in the low demand areas and it does not create an incentive to guide the spectrum utilization to the high value users in the high demand areas.

The population density describes well the demand for traditional mobile network spectrum as the end customers are consumers. A significant customer group of private LTE are expected to be industrial estates like factories or ports. No one lives in factories or ports. The main research question to be studied further is how to quantify the demand of the industrial estates in private LTE pricing.

We could summarize the recommendations for private LTE pricing of spectrum licenses in 3.5 GHz band as follows: have a significant recurring payment, use block licenses, make the license price highly dependent on the population density, set the pricing for the lowest demand areas at nominal level, set the AIP fee level to the benchmark auction price, use benchmarking analysis to estimate the auction price, and use a factor to take into account the demand at industrial estates. Spectrum policy and regulation can be a trigger for novel private network ecosystem. Simple authorization processes reduce the cost and minimize the complexity of private LTE spectrum use.

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