Valuation of Flexible Spectrum Licensing for Local 6G with Varying Interference Levels

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***Abstract*—This paper claims the need for introducing more flexibility to licensing conditions for local 6G networks, which considers varying levels of interference levels and related spectrum valuation. First, we discuss existing spectrum access models and approaches for the valuation of local licensing. Then, building on the pluralistic licensing concept, we claim that introducing spectrum valuation based on interference level coordination could achieve an efficient spectrum assignment. Such an assignment requires coordination, and it is especially suitable for local spectrum licensing, involving both horizontal and vertical spectrum sharing, since the limited number of spectrum license holders makes it easier to coordinate interference.**

Keywords—flexible licensing, pluralistic licensing, usage-based valuation, interference coordination, local 6G networks, spectrum sharing, 6G.

I. INTRODUCTION

The value of the radio spectrum can be determined via its relative worth, utility, or importance to a stakeholder and is therefore contextual, defined by demand or need, and may evolve over time [1], [2], [3]. Given the dynamic nature of spectrum valuation, market-based mechanisms have been utilized for cellular mobile communication systems through auctions at a national level [4]. Traditional approaches to spectrum licensing have considered static protection from harmful interference to be the target state, which has come with the price of high bidding over competitors to gain exclusivity. This has led to over-bidding if demand is higher than supply as happened in some spectrum auctions for 3G and 4G [5].

Local spectrum licenses [6] have appeared to allow spectrum access in smaller areas, especially for local mobile communication networks including 4G and 5G. The demand and usage of local spectrum licenses can drastically change between the different locations and types of use, and therefore, valuation and pricing schemes at a local level should not follow the same logic as spectrum access rights for wide areas. In fact, spectrum auctions work only when licenses are liquid including many potential buyers [7], which often is the case for nationwide licenses. However, when licenses are local, the local demand for spectrum can be considerably different in the different locations including locations where there are just few or one interested stakeholder for accessing the spectrum.

6G is expected to deliver a wide variety of use cases, many of them deployed in geographically limited areas. Local access to spectrum calls for local valuation of spectrum, which should consider the particular characteristics of the planned deployment. Local 5G deployments have emerged to serve different location specific needs [6]. They can be deployed under different spectrum authorization models whereof local licensing has become a key mechanism in several countries [8]. Regulators have particularly adopted administrative allocation approach for local licensing to follow first come first serve models with fixed pricing making local market entry predictable [9].

When there is more demand for local spectrum access than supply, the first come first serve model has limitations. It is challenging for a central entity, such as the regulator, to capture the usage-based valuation of each assigned spectrum band. A secondary market with clear rules may be an attractive alternative for achieving an efficient assignment over time. However, such a marketplace for trading spectrum access rights locally would require an accurate and cost-effective mechanism, to act as a market enabler.

Previous literature has proposed flexibility to spectrum awards with the concept of *Pluralistic Licensing* [10], [11]. Pluralistic Licensing allows the entrant to choose between different levels of interference in the licensing conditions, paying a license fee that is related to the accepted interference.

Expanding the Pluralistic Licensing concept, this paper proposes to introduce varying interference levels and related valuations into the spectrum assignment in the 6G era to establish local networks by different stakeholders. The proposed approach expands traditional local spectrum licensing for 5G to exhibit varying levels of interference for potential incumbent spectrum users as well as other local licensees in the 6G era. By letting each local network define the allowed interference level, each spectrum license holder reveals its valuation for that spectrum and pays accordingly. Such interference definition should happen as a result of a coordination process between adjacent networks. The logic behind such spectrum assignment mechanism belongs to the field of transaction costs economics [12].

The rest of the paper is structured as follows. Section II describes the existing valuation options for local spectrum. Section III discusses the economic theory related to spectrum transactions. Section IV presents the proposal for local spectrum assignment; section V exemplifies through a simulation and section VI concludes.

II. Existing local spectrum licensing models and related valuation

A. *Local spectrum licensing options*

Local spectrum licensing is about defining spectrum property rights over a geographically restricted area with predefined interference conditions and awarding these rights of use to a stakeholder. It typically involves some type of spectrum sharing, where two or more radio systems operate in the same frequency band [13]. In general, there are two main categories of spectrum sharing, namely horizontal and vertical spectrum sharing. *Horizontal spectrum sharing* refers to the situation where different radio systems are operating in the same band with similar levels of spectrum access rights [13]. *Vertical spectrum sharing* refers to the situation where the radio systems have different levels of spectrum access rights [13]. In realistic spectrum-sharing situations, both horizontal and vertical spectrum sharing are typically present, see e.g., [14].

Administrative allocation is a form of hierarchical command and control approach, where the regulator defines spectrum usage rights and awards them to applicants based on some criteria. Administrative allocation dominated as the regulators' mechanism to assign spectrum access rights over a long time [15], [8]. Administrative allocation typically uses beauty contests, first come first serve, or other types of direct awards, where the regulator assigns spectrum access rights to applicants. 5G spectrum authorization decisions have introduced *local licensing* schemes in several countries, where the regulator issues local spectrum access rights directly to different stakeholders to deploy their own local networks [16]. This has allowed different stakeholders to apply for local spectrum access rights, opening the traditionally closed mobile communication market to a variety of players.

Market-based mechanisms have replaced administrative allocation in many countries in assigning access rights for public mobile communications [17]. Market-based mechanisms determine spectrum property or usage rights and grant licenses to use the radio spectrum to a limited number of applicants through some market mechanisms. The most common mechanism is competitive spectrum auction [4]. However, due to the small value and illiquidity of licenses for local networks, auctions are often not a viable method of pricing for local licensing [7]. It is reasonable to assume that in many locations the number of potential buyers per specific local 6G case is relatively small, e.g., in the vertical and enterprise licensing cases, because the licenses are local, and they benefit only a few buyers. For example, in a case where a factory or a harbor wants to deploy a local network to its own property, there are no other buyers because the property is only used and/or controlled by the facility owner.

The *leasing* of licensed spectrum that has been awarded through market-based mechanism has been possible in EU, US and several other countries with a variety of national regulatory approaches, see e.g., [18]. Leasing refers to the situation where the original holder of spectrum access rights transfers the rights to another stakeholder. The negotiated price is impacted by the current license holder's own license cost, need for using the spectrum, competition situation as well as strategic position on whether to open the spectrum for use by others. In the case where local spectrum access rights are acquired from an MNO through leasing, different approaches for defining the rules and conditions as well as pricing for accessing the band may be used. To date, local secondary spectrum exchange has been seldom used due to regulatory friction and existing transaction costs.

The *virtual mobile network operator* (VMNO) model [19] is not a specific spectrum access option as such but more like a collaboration model between stakeholders such as MNO and the local service provider. In this model, the MNO provides a spectrum bundled with network services for the vertical service provider.

The *unlicensed commons* approach allows unlicensed devices to access the radio spectrum without defining spectrum property rights and to operate under given regulator-defined rules and conditions, often on a low-power basis [20]. The unlicensed commons approach promotes innovation and competition, and the spectrum is typically free of charge. For example, the unlicensed 5 GHz band is available globally utilizing RLAN and unlicensed 4G and 5G standards.

Finally, the *Pluralistic Licensing* concept has been presented in the literature as a means to include varying interference levels as a characteristic of the licensed spectrum, as shown in Fig. 1, where a licensee can accept, for example, a higher level of interference in exchange for a discounted fee.

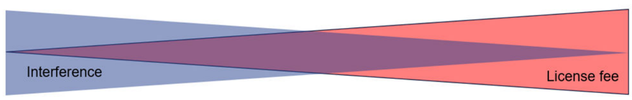

Fig. 1. The Pluralistic Licensing concept [10].

Regarding local licenses, in the EU, two main methods have been used [21]: 1) assignment to MNOs with a lease obligation for local vertical use and 2) Direct assignment to verticals of local spectrum. Overall, approaches to local licensing have been versatile in the EU, where some countries have developed and adopted rules in different bands, while others have not introduced local licensing. In the US, the FCC had to adjust the rules for accessing the CBRS band (a 150 MHz wide band in the 3.5 GHz frequencies) to provide better incentives and certainties for making investments [22]. This evidences that too dynamic access rules may bring uncertainties to investors (US case), while too restrictive rules do not provide an incentive for obtaining an efficient usage of the spectrum. Moreover, most mobile markets comprise just a handful of spectrum license holders in each band who often view spectrum as a strategic asset that enhances their competitive positions in the market and may consider the option value arising from uncertainty related to no longer having access to the spectrum asset too high. Further friction is caused by the information asymmetry problem between the regulator and operators, and substantial differences in business cases among operators and potential new entrants [23], [24], [25].

B. Valuation and pricing of spectrum

This section describes the different options for spectrum pricing and valuation. Spectrum valuation can be understood from several perspectives, which are presented as follows [8]. From an engineering value, spectrum valuation refers to the savings in total cost of ownership from obtaining additional spectrum for providing a service. From an economic value, spectrum valuation emphasizes the expected profits from the offered services. A strategic perspective considers the expected market position as a result from obtaining a spectrum. Typically, the most used is the economic value, as it represents the most common spectrum license holder perspective.

From a pricing perspective, efficient prices should reflect the valuations of buyers. According to [3], firms can differentiate by price along the following five dimensions: scope, information base, influence, formula, and temporal rights. Scope refers to the granularity of the offer (package versus unit). Information base refers to what type of information dominates the pricing decision, which can be, for example, based on cost, competition, or customer value. Influence refers to who can influence the price; for instance, in a price list, sellers set the price according to their own criteria. The price can also be the result of a negotiation, as a result of an auction, or it could be defined according to external circumstances (exogenous). The formula describes how the price relates to the volume, for instance, the price could be fixed regardless of the volume, it can be a price per unit, or combine both fixed and per unit modes. Finally, temporal rights define the period of usage, which can be perpetual, time-limited (leasing, rent or subscription), or paid per use (for every occasion).

III. SPECTRUM LICENSING BASED ON SPECTRUM VALUATION

From a transaction cost economics perspective, the assignment of radio spectrum can achieve an efficient outcome through a market-based mechanism, in which interested parties are able to trade between them with zero transaction costs and where the property (or usage) rights of the spectrum are well defined (i.e., Coase theorem) [12]. In a local licensing environment, this could imply that licensees should be able to negotiate with their neighbors, including both incumbent spectrum license holders and other local licensees, on the required quality of the licensed spectrum so that the usage of such a spectrum achieves an efficient assignment. One main characteristic of the traded spectrum should be the interference levels from adjacent areas, which are naturally dynamic in time.

To describe the idea of introducing local license flexibility with the pluralistic licensing approach, let's assume two neighboring licensees, local networks 1 and 2, which have a demand for their services D_{LN1} and D_{LN2}, and share the same frequency band in adjacent areas (Fig. 2). They can be two local spectrum license holders (horizontal sharing). To achieve efficient usage of the shared spectrum, they can negotiate on the needed quality of spectrum, meaning that a higher quality in terms of SINR (signal-to-interference-and-noise ratio) for one party results in a lower quality for the other party, since the spectrum is shared. Therefore, if the total available quality is $SINR_{MAX}$, such amount will be divided into two, the first getting SINR*, and the other ($SINR_{MAX}$ – SINR*). Let´s assume that the demand for quality increases for LN_1, so that $D'_{LN1} > D_{LN1}$; in that case, LN_1 will buy more quality (more transmission power for LN_1 or less interference from LN_2, among other possible parameters) from the neighbor since LN_1 values the available quality more than LN_2. There will be a transaction between local networks 1 and 2 at price p**, which is higher than the valuation of LN_2 for that quality. If the cost of making this transaction is low, this market will be efficient, and it will dynamically reallocate the spectrum resources according to the changing demands.

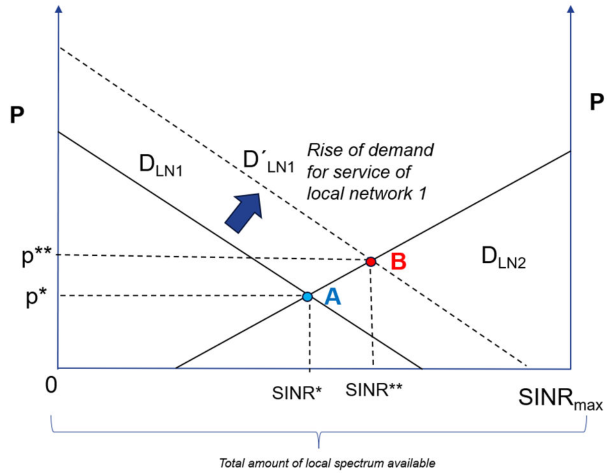

Fig. 2. Local transaction between neighbor licensees.

However, in practice, a market-based assignment could not achieve an efficient outcome under the existence of transaction costs. In the absence of a well-defined market mechanism, the following transaction costs arise [26]:

- Search and information costs: associated with determining the available spectrum in the market and its characteristics (in quality, quantity, terms, price, etc.)
- Bargaining costs: required to come to an acceptable agreement, drawing up an appropriate contract from a business and regulatory perspective.
- Policing and enforcement costs: associated with keeping the terms of the contract and enforcing its fulfillment. It is often related to the regulatory and legal system.

When a market mechanism is already in place, less explicit transaction costs could still exist [27]:

- Frequency: high frequency of transactions increases costs. If changes in the demand are volatile, the volume of transaction makes it difficult to achieve an optimal assignment.
- Uncertainty: environmental changes and uncertain behaviors of other neighbors increase costs of transactions. This may be the case for a dense area with many neighbors.
- Asset specificity: high specificity of assets increases the possibility of opportunistic behavior of other parties. For instance, an MNO having a dominant position in the market may not be willing to have competition.

The above-mentioned issues make it difficult to establish a dynamic market-based mechanism for spectrum transactions nationwide; however, on a local basis the uncertainty is lower, and the neighboring characteristic of the involved parties may decrease the costs associated with negotiation between parties if the terms of the transaction are clearly defined.

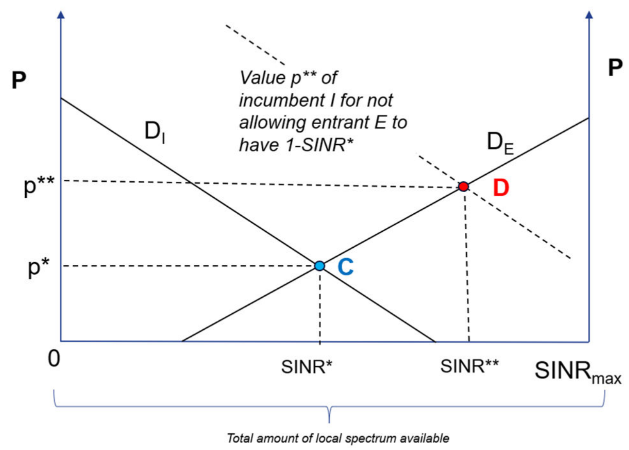

Fig. 3. Vertical spectrum sharing and incentives for keeping spectrum unused.

One particular challenge may happen with vertical spectrum sharing, where one incumbent spectrum license holder (e.g., MNO) has a dominant position in the market and may not be willing to allow a new entrant (i.e., local operator) to use spectrum. Fig. 3 describes such a situation, where an optimal spectrum allocation for a certain frequency band is SINR* and (1-SINR*). Even though this allocation corresponds to the valuation of each operator, the incumbent may not be willing to provide access to the new entrant, and for example, maintain enough spectrum for SINR** (>SINR*), even though it is not needed. In this way, the incumbent reduces the quality of spectrum for the new entrant to 1-SINR**, causing higher costs and prices for the new entrant, and avoiding an increase in competition in the local market. In this case, the unused spectrum has a higher value to the incumbent than p* (p**), which is the private value for not allowing the entrant to obtain 1-SINR*.

The above-mentioned problem may arise when the initial allocation of spectrum is highly concentrated, as such a situation may provide incentives for reducing competition by keeping spectrum unused. In such a case, the regulator should diminish the concentration of the spectrum, by imposing sharing obligations for the unused spectrum for the MNOs (such as in several European countries) [21], or by establishing a mechanism in which a mediator facilitates spectrum transactions (CBRS SAS in the US) [28].

IV. Proposed Pluralistic Licensing Approach for Local Mobile Communication Networks

Next, we introduce our proposal for local spectrum assignment for mobile communication networks, based on the pluralistic licensing concept, in which each spectrum license holder chooses its allowable level of interference as a result of a negotiation. In this process, spectrum license holders reveal to each other their valuation of the spectrum, and prices should be linked with their valuation in a secondary market. In some locations, it may happen that no or very little coordination is needed, since spectrum demand is low. However, in other cases, adjacent networks may require spectrum with high level of protection from interference, or at least certain level of coordination. If the demand for interference protection is high, the resulting price should be higher, as shown in Fig. 1. Thus, the implementation of a local spectrum assignment based on pluralistic licensing concept requires a negotiation mechanism to agree on the allowable interference levels between spectrum holders based on local conditions.

In the proposed pluralistic licensing approach for local mobile communication networks, spectrum holders coordinate and negotiate interference based on own valuation of the available spectrum. Fig. 4 shows how a pluralistic licensing concept could stimulate coordination for local networks and facilitate spectrum transactions. When licenses are exclusively assigned, there is no need for coordination since a spectrum band is exclusively used by one single operator. Exclusively assigned spectrum is especially suitable for low frequencies since they cause interference over larger distances. On the other hand, the unlicensed commons model does not protect or claim protection from harmful interference. It is especially suitable for higher frequencies where interference remains local. When spectrum is authorized under the unlicensed commons model, coordination between users is typically low. When licenses are locally assigned, being at a campus, building or even household level, there is a higher need for coordination as interference could generate harm and coordination between a limited number of neighbors is still relatively feasible. Coordination costs can increase with the number of spectrum license holders and with the frequency bands (higher for lower frequencies, since the transmission interferes with more neighbors). Therefore, the implementation of the pluralistic licensing concept is suitable for local spectrum assignment, starting for those cases with lower number of spectrum license holders (local horizontal and vertical spectrum).

Recent technological developments related to 6G can gradually decrease the level of interference (such as massive MIMO and reconfigurable intelligent surfaces) and achieve better coordination (integrated sensing capabilities, AI-based interference management) between adjacent networks [29]. This reduction in interference levels between different networks will enable to gradually apply the pluralistic licensing to a wider number of cases. However, at the first stage, local licensing presents lower coordination costs. With the automation of interference management, the time length of transactions can be made shorter and provide higher flexibility without the risk of opportunistic behavior from adjacent networks. This paper supports the idea of going to a more flexible regime, starting with local deployments.

Fig. 5 presents an analysis on how different spectrum licensing options are compared in terms of pricing, from the perspective of the dimensions of price differentiation [3]. In administrative allocation, general spectrum pricelist models typically used by regulators consist of the following per unit 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. Pricing scope is attribute-level unit of the offer priced individually. The pay per use price model can be utilized e.g., in program making and special events.

Market-based mechanisms take the value of spectrum into account and incentivize more efficient spectrum use. Access rights awarded through market-based mechanisms often allow secondary markets for spectrum, where the original spectrum property rights can be traded or leased in whole or in part by geography, bandwidth or by both for a given duration.

Leasing model is typically based on the customer valuation that assesses the value of spectrum from a commercial perspective estimating profit the spectrum in question will generate for an operator over the license term. Modeling requires a significant amount of information such as: total revenue estimated based on current and future demand, market and competition, network infrastructure costs, and non-network operational expenses.

In VMNO, result-based pricing stemming from some observable outcome of the use of the spectrum and network resources can be utilized. This will be within the control of the buyer and necessitates some agreed mechanism for determining the result. Temporal rights could be subscription-based transferring the right to use a bundled service for a specified time including upgrades and enhancements.

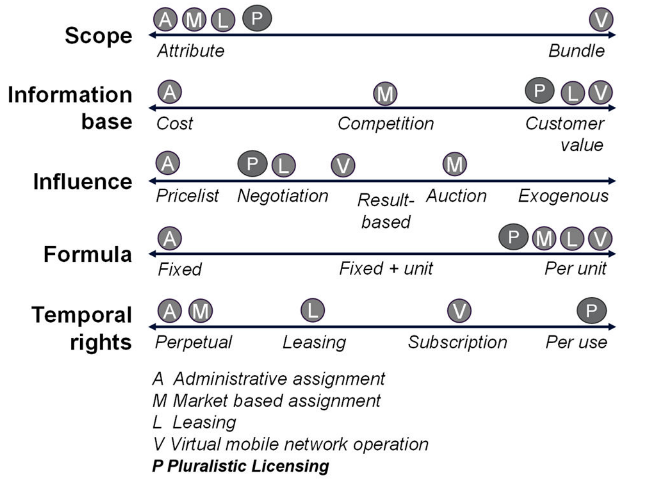

Fig. 5. Comparison of pluralistic licensing against other licensing options from a pricing perspective.

We can observe that pluralistic licensing brings the benefits of a market-based assignment mechanism for local networks in terms of the information utilized for valuation, without the need for spectrum auctions and the related risk of overbidding. At the same time, pluralistic licensing may provide flexibility in terms of temporal rights as it allows dynamically to adjust spectrum usage allocation in time. The concrete time scale is still decided between involved spectrum license holders, as enabled by the automation of the process. In terms of pricing formula and influence, pluralistic licensing approaches a leasing mechanism.

V. SIMULATION EXAMPLE

We show a simple simulation example to illustrate a spectrum-sharing scenario. Let's assume two spectrum license holders in nearby indoor areas, which can be industrial or residential. Both are transmitting indoors, but areas are near enough so that each one suffers from the interference of the other. Table I shows the main assumption of this simulation example and Fig. 6 presents a schematic explanation of the model, where interference within the same network can be

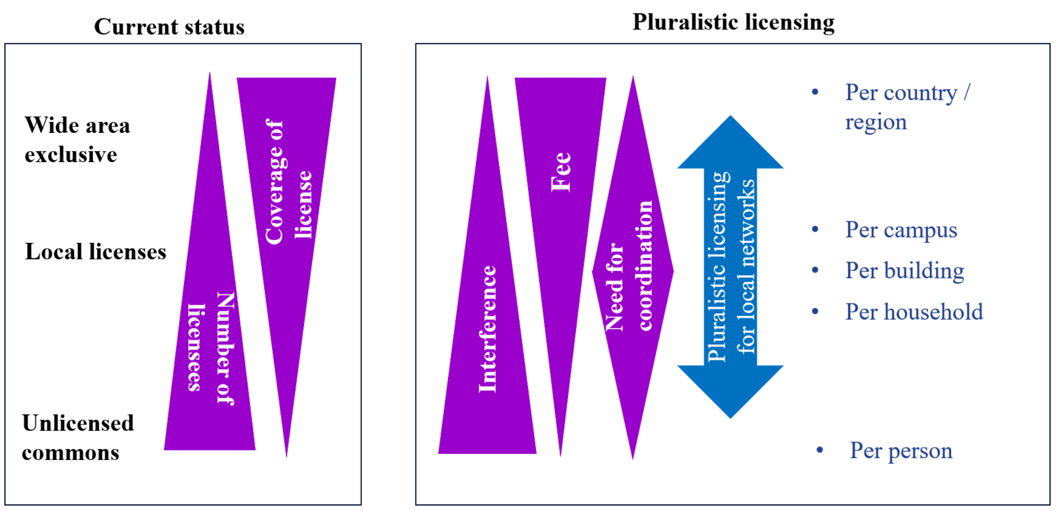

Fig. 4. Pluralistic licensing as a means for providing the incentives for quality of local networks.

coordinated (orthogonal signals); however, interference comes from another local network.

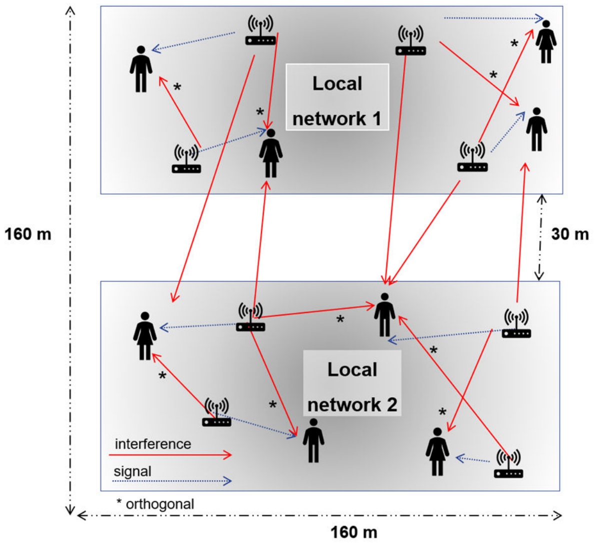

Fig. 6. Example of interference scenario with two adjacent in-building areas.

TABLE I. ASSUMPTIONS OF THE SIMULATION EXAMPLE

ASSUMPTIONS	
Separation between buildings	30m
BS transmission center frequency	2.5 GHz
BS transmission power	18-24 dBm
Terminal transmission power	21 dBm
Antenna gain	2.1 dB
Path loss model from Base Station to terminal in same zone	In-building propagation model [30]
Path loss model from Base Station to terminal from adjacent zone	In-building propagation model [30] with wall penetration
Noise power	-101 dBm / 0.008 pW
BS effective height	1.5 m
Terminal effective height	1.5m

Fig. 7 shows the results for this simulation example in terms of perceived average SINR for users belonging to a local network, under different combinations of transmission power from base stations. These results depict how further efficiency can be achieved through coordination between the involved parties (i.e., networks), depending on their valuation of the spectrum, increasing the value and utilization of the spectrum. For example, in the figure, two local networks can transmit with 18 dBm achieving an average of user perceived SINR of 20,4 dB (point A). However, if one transmits with 21 dBm, will increase its perceived QoS, while the other will decrease (point B). These points (A and B) are depicted as equilibrium between the demand curves of neighboring networks in Fig. 2. If we assume that the requirements from each side are dynamic in time, it may not be possible to obtain an efficient allocation of spectrum between two local networks with varying conditions without each party knowing the information of each other, and therefore an efficient spectrum allocation requires a higher level of automation in highly volatile scenarios. However, with a small coordination is still possible to considerably improve the allocation of spectrum by knowing the valuation (and requirements for quality) of the other party. By allowing coordination and negotiations between involved parties, spectrum allocation is improved, and any additional improvement in the information exchange and in the automation of the process will positively impact the spectrum allocation further. Thus, the frequency of spectrum transactions is decided by the involved parties as allowed by technology.

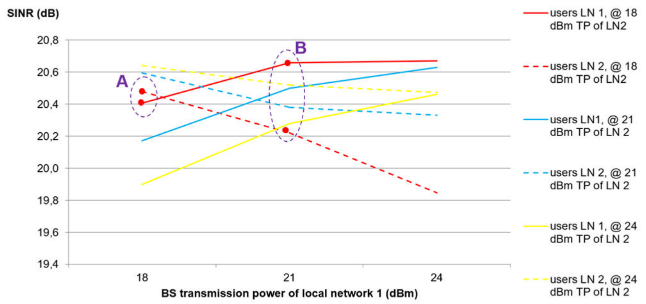

Fig. 7. Different trade-offs between two groups of users from local networks (LN) 1 and 2 with varying transmission power from base stations. A and B depict the equilibriums from Fig. 2.

The depicted scenario is still relatively simple as compared with a vertical sharing scenario between one MNO and several adjacent local operators. However, as coordination between spectrum license holders is gradually achieved, more transaction scenarios could be enabled, starting with the simplest ones.

VI. CONCLUSIONS

This paper has proposed the introduction of higher flexibility into local spectrum licensing in the 6G era by considering varying levels of interference and related spectrum valuations. A spectrum market that coordinates interference levels can facilitate spectrum transactions based on spectrum license holder valuations on spectrum quality, which can enable efficiency in spectrum allocation over time. Introducing different levels of interference as a characteristic of the assigned spectrum has been suggested before by the pluralistic licensing concept. This paper expands the idea for local 6G networks and claims that additional license flexibility in terms of varying interference levels and related valuations should be considered in 6G. In addition, the latest development of 6G related to sensing and AI-based interference management could facilitate further coordination if it is done in an automated fashion. However, the reduced number of spectrum license holders makes it easier to coordinate interference levels locally, both for horizontal and vertical spectrum sharing cases. Finally, the regulation should put emphasis on the initial spectrum market concentration to avoid anti-competitive behavior.

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