On the Engineering Value of Spectrum in Dense Mobile Network Deployment Scenarios

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Abstract**—the continuing growth in the mobile data traffic magnifies the challenges for the design and deployment of scalable high-capacity mobile networks that can meet the future demand at reasonable cost levels. In order to meet the future traffic demand, an operator should invest on both infrastructure, i.e. densification of base stations, and more radio spectrum. Knowing the effectiveness of each element is thus of utmost importance for minimizing the investment cost. In this paper, we study the economic substitutability between spectrum and densification. For this, we measure the engineering value of spectrum, which refers to the potential saving in the total cost of ownership (TCO) as result of acquiring additional spectrum resources. Two countries are considered to represent different market situations: India with dense population and high spectrum price and Sweden with moderate population density and low spectrum fee. Numerical results indicate that additional amount of spectrum substantially relieves the need for densifying radio base stations, particularly for providing high user data rate in dense India. Nonetheless, the engineering value of spectrum is low in India (i.e. spectrum acquisition has less cost benefit) under the high spectrum price of today, whereas spectrum is instrumental in lowering the total cost of ownership in Sweden. Our finding highlights the importance of affordable and sufficient spectrum resources for future mobile broadband provisioning.**

Keywords- economic value of spectrum, mobile broadband, MNO, Total Cost of ownership (TCO),

I. Introduction

The design ambitions of the future mobile system has set a targets for 10 to 100 times more average date rate per end-subscriber and 1000 times more network capacity compared to today's mobile networks. Under specific radio access technology constraints, the mobile network operators (MNOs) have two investment options to provision the targeted service experience by end-subscriber; i.e. either to increase radio base station density or to acquire more spectrums. However, these two investment options cannot be exchanged linearly to provision the targeted average data rate in dense deployment regime as shown by the work in [1] and [2]. In the dense regime, the density of radio base station will be equal or larger than the active mobile subscribers. In such dense regime, more spectrum resources will be required to reach the targeted higher average data rate per active subscriber in future mobile systems as indicated in [1]. The results in [1] and [2] can be linked to the ongoing discussion about the required amount spectrum for mobile services in horizon 2020 [3].

In view of technological and regulatory development, various forms of spectrum authorization options are discussed based on exclusive use or on shared use basis [4] [5]. In other words, the MNOs could have three possible spectrum expansion options namely; 1) the use of more licensed spectrum resources (i.e. to acquire new spectrum licenses), 2) the sharing of the existing licensed spectrum resources with other mobile operators and 3) the access of more spectrum resources in non-communication actors spectrum bands based on secondary use concept. Yet, the realization and valuation of a specific spectrum expansion option remains bounded by number of factors such as the mobile MNO's business strategy, technological advances, and surrounding regulation environment.

Traditionally, the cost-equivalent exchange ratios between resources expended and benefits received in different market conditions, also known as the opportunity cost, is considered as the main metric for evaluating the value of spectrum resources. For example, Plum presents a review of the value of spectrum licenses, model values based on expected revenues and costs for a hypothetical operator in [6]. In this context, the increment in the total cost of ownership (TCO) per unit of additional average data rate per active subscriber is normally considered as equivalent of value of added resources (i.e. spectrum or infrastructure). Similarly, the Australian government [7] applies an opportunity cost modeling, which it defines as the highest value alternative forgone, but underscores that the opportunity cost pricing differs according to circumstances. While, Yeo, et al in [8] estimates spectrum values based on calculations from auction data and with an analysis of observed bidding behavior through an econometric model. Similarly, the authors in [9] and [10] studied the value of aggregating spectrum resources from the perspective of the mobile operator focusing on anticipated engineering and strategic values. The main conclusion in [9] and [10] indicate that access to sufficient spectrum resources is a prerequisite to be competitive on the mobile broadband market by provisioning higher data rates at reasonable production cost.

In this paper, we aim to answer if it is possible for the existing MNOs in the market to implement an economically viable provisioning strategy in horizon 2020 or not. In this regard, the minimum feasible combinations of spectrum resources and radio base stations to provision the targeted average data rate per subscriber is discussed in view of today's spectrum holding and radio access technology. First, the objective is to investigate when the mobile operators will start to experience a diminishing return from the densification under specific average spectrum holding. Then, the potential savings in the total cost of ownership, i.e. "engineering value" facilitated by acquiring additional spectrum, is studied considering historical spectrum auctions in the two markets under study namely; India with dense population and high spectrum auction price and Sweden with moderate population density and lower spectrum fee.

The rest of the paper is structured as follows: Section II provides descriptions of the considered deployment scenarios and assumptions. Sections III, describes the adopted total cost of ownership model along with the necessary assumptions. Section IV discusses the results obtained along with additional qualitative discussion. Section V highlights the main conclusions derived.

II. Deployment Scenarios and Assumptions

In this study, the cost of provisioning mobile broadband services in two different urban areas of one square kilometers is investigated. The assumptions about the mobile broadband traffic demand in theses aforementioned geographical areas have been related to the market situation in two countries namely: A) India with dense population (around 10000 inhabitants per km^2) and low spectrum holding per mobile operator (around 10 MHz) and B) Sweden with moderate population density (around 2000 inhabitants per km^2) and high spectrum holding per mobile operator (around 60 MHz).

A. Demand Side

The demand levels for mobile broadband service (D_{level}) in the different countries and urban areas under study is estimated as shown in Eq.1.

$$D_{level} = N_{user} R_{user} \quad (1)$$

Where N_{user} represents the number of active mobile subscribers during the peak hour in one square kilometer and R_{user} is the targeted average data rate per user. The number of active subscriber is estimated as function of the mobile operator market share and activity factor of the mobile subscriber. As per Earth project around 10-30% of the data subscribers are considered to be active in the peak hours in today mobile network. Hence, activity factor of 25% is assumed in this study [11]. Moreover, an average data rate of 0.5 Mbps is assumed for today network and target of 10 to 100 times more increment is assumed in year 2020 based on the defined test cases within the course of the FP7 project ‘METIS’ [12].

B. Supply Side

In the macroeconomic theory, the production function is normally defined by a mathematical expression that describes the relationship between amount of used input and produced output in term of products or services. In the wireless network context, the production function to provision specific average data rate per user can be estimated as function of the average spectral efficiency per cell and the amount of the allocated bandwidth per cell as shown in Eq.2 [13] [14].

$$C = \eta BW_{sys} ASE \quad (2)$$

For the purpose of this study, the average spectral efficiency can be estimated based on the developed close-form in [2]. Accordingly, the provisioned average data rate per user in the targeted service area can be approximated as shown by Eq.3.

$$C = \eta BW_{sys} \int_0^{\infty} \left[1 + \rho_t (e^t - 1)^{\frac{2}{\alpha}} * P_{active}\right]^{-1} dt \quad (3)$$

Where η represents the spectrum reuse factor, BW_{sys} represents the allocated amount of spectrum per mobile operator and α represents the path loss exponent in the used standard power loss propagation model, while P_{active} is the probability that a radio base station is turned-on (i.e. the radio base station has a mobile subscriber to serve) which can be determined as a function of the number of deployed radio base station N_{RBS} and number of active concurrent mobile subscribers N_{users} as shown in Eq. 4.

$$P_{active} = \left(1 - \left[1 + \left(\frac{N_{users}}{3.5 * N_{RBS}}\right)\right]^{-3.5}\right) \quad (4)$$

and where $\rho_t = \left(\int_{(e^t-1)^{-\frac{2}{\alpha}}}^{\infty} \left[\frac{1}{1+u^{\frac{2}{\alpha}}}\right] du\right).$

TABLE I: COST (CAPEX AND OPEX) ASSUMPTIONS

Item	Cost (k€)	Source
Cost of Outdoor Smallcell	10	[15]
Backhaul link cost	4	[9] [10]
Annual Site rent	3	[9] [10]
O&M represent 10%(of CapEx) and installation 5%(of CapEx)		

C. Economic Theory of Efficient Production

The efficient production region can be defined as the operation region where the minimum possible combination of inputs is used to achieve the targeted output level [13] [14]. In wireless context, this can be interpreted as the optimum combination between the spectrum resources and number of deployed radio base stations so that targeted average data rate per subscriber is provisioned as shown in Eq. 5.

$$\left\{ \begin{array}{l} \min(BW_{sys},\ N_{RBS}), \\ \\ Subject\ to \quad C \geq R_{user} \end{array} \right\} \quad (5)$$

To find the point where the minimum combination of the inputs is occurred, the elasticity of substitution σ can be used to reflect the shape of the production function and the degree of substitutability between the used inputs. The elasticity of substitution σ can be calculated as shown in Eq.6 [13] [14].

$$\sigma = \frac{\%\left(\frac{[\Delta BW_{sys}]}{[\Delta RBS]}\right)}{\%(\Delta MTRS_{RBS-BW})} \quad (6)$$

The marginal rate of technical substitution ($\mathrm{MTRS_{RBS-BW}}$) reflects the possible reduction in the number of radio base stations (ΔN_{RBS}) as result of using additional spectrum resources (ΔBW_{sys}) while keeping the same level of output as shown in Eq.7.

$$MTRS_{RBS-BW} = -\frac{\Delta RBS}{\Delta BW_{sys}} \quad (7)$$

Based on Eq.5 and Eq.7, the radio access network (RAN) can be dimensioned in terms of the required number of radio base stations (N_{RBS}) and backhauling links *(*N_{BHL}*)* considering specific spectrum allocation *(*BW_{sys}*)* per mobile operator. First, the number Radio Base Stations *(RBSs)* is calculated based on the targeted average data rate per mobile subscriber (R_{user}). Then, the number of required backhaul links can be estimated as function of the number of active mobile subscriber during the busy hour (N_{user}), the average data rate per subscriber R_{user} and the maximum capacity per backhaul links *(*$\mathrm{C_{BH}} = 1.2$ Gbps) as shown in Eq.8.

$$N_{BHL} = \left[\boldsymbol{Ceil}\left(\left[\frac{R_{user}\ N_{user}}{C_{BH}}\right]\right)\right] (8)$$

III. Total Cost of Ownership (TCO)

The total cost of ownership (TCO) can be calculated in terms of the annualized investments and operations costs for a period of 10 years i.e. from year 2015 to year 2025 based on the assumption in Table I. In this regard, the net present value (NPV) method is used for this purpose by considering a discount rate of 10%, as shown in Eq.9.

$$TCO = \sum_{t=1}^{T} \frac{TCO_t}{(1+r)^t} \quad (9)$$

Where TCO_t represents the annualized total cost of ownership in terms of the annualized CapEx and annualized

OpEx at year *t*, while *r* represents the discount rate and *T* represents the network operation period in number of years. The annualize capital expenditure for both of the radio access part and backhauling part (backhaul network) is composed of the inquired costs per radio sites and backhaul links in terms of telecom equipment cost, auxiliary systems cost, civil and construction works cost in addition to the associated installation and commissioning costs. In this regard, the annualize capital expenditure C_{CapEx} is calculated as shown in Eq. (10); where C_{BS} and C_{BHL} are the incurred cost per a radio site and backhaul link respectively. While C_{BW} represents the paid annual spectrum fee.

$$C_{capex} = N_{RBS}C_{BS} + N_{BHL}C_{BHL} + C_{Ins} + C_{BW} \quad (10)$$

On other hand, The operation expenditure (OpEx) in the radio sites and the backhaul network is composed of the cost of annual operation and maintenance (O&M) including the electricity bill and radio sites rent cost (C_{Rsite}) as shown in Eq.11.

$$C_{Opex} = C_{O\&M} + CR_{site} \quad (11)$$

IV. Results and Discussion

Under certain technological and regulation constraints, the mobile operator has only certain operation region that contains all the possible combinations of spectrum resource and radio base stations densities. As shown in Fig.1 and Fig.2, the average spectrum holding per mobile operator is the main determinant of the cost effective operation region. Considering the current spectrum allocation per operator in Sweden, which ranges between 20 to 60 MHz per operator, the mobile operators need to deploy around 200 to 700 radio base stations per one square kilometer to provision an average data rate per mobile subscriber in order of 10 Mbps as shown in Fig.1. For high spectrum holding (i.e. 60 MHz), the average data rate per subscriber increases proportional to change in the radio base station density or the densifications level as shown in Fig.1. In other words, doubling the radio base density will result in doubling the achieved data rate per subscriber. However, the mobile operator will start to experience progressively smaller or diminishing increases in achieved average data rate per subscriber for lower spectrum allocation.

By decreasing the average spectrum holding to around 20 MHz, the Swedish mobile operators will need to triple their radio base station density in order to double the experienced average data rate per subscriber as shown in Fig.1. In other words, the Swedish operator will start to operate in dense regime. For the same average spectrum holding, the relative increase in the densification level compared to achieve increment in the average data rate is similar in both of the Indian and Swedish market as shown in Fig.1 and Fig.2. Yet, the absolute number of the required radio base station is different in both markets. In this context, the mobile operators in India need to deploy around 3,000 to 7,000 radio base station per square kilometers to achieve an average data rate in order of 10 Mbps as shown in Fig.2. Moreover, the lower spectrum holding in India will lead to considerable increase in the radio base station density as higher average data per subscriber is targeted which could means considerably high provisioning cost. In this regard, securing sufficient amount of spectrum becomes more important to avoid the operation in dense regime.

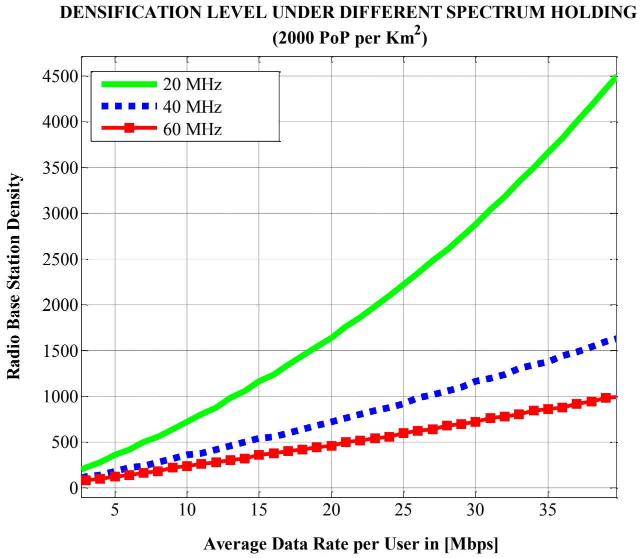

Figure 1: Densification Level in Sweden

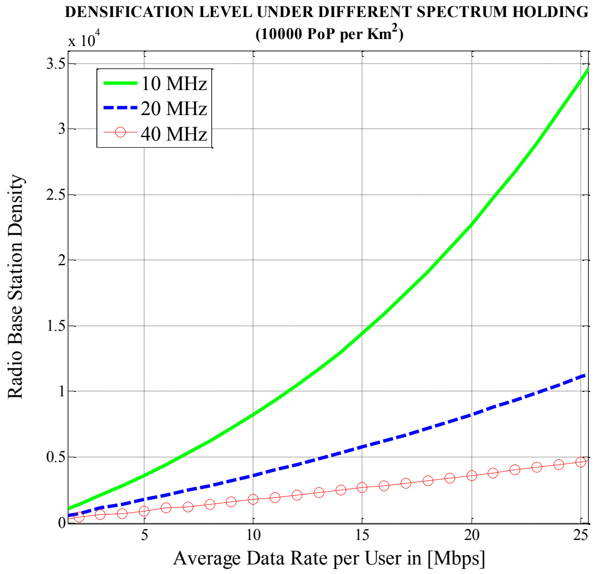

Figure 2: Densification Level in India

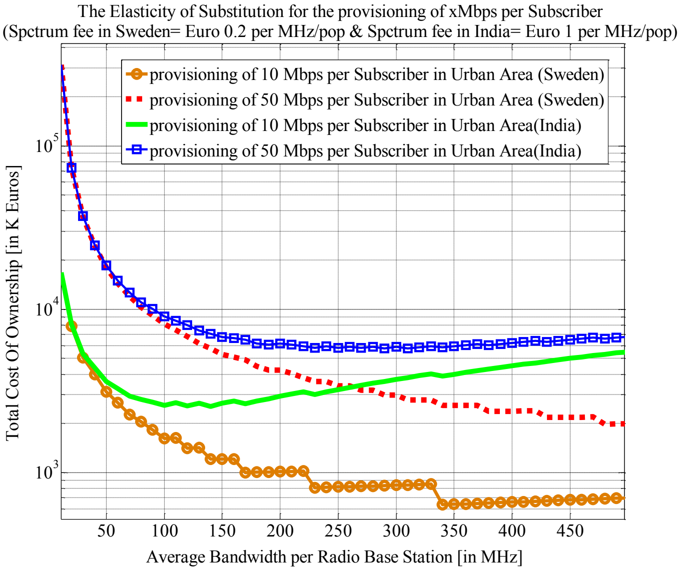

Figure 3: elasticity of substitution

As shown in Fig.3, the elasticity's of substitution provide a powerful tool for evaluating the engineering value of spectrum. For the purpose of this study, the estimation of the licensed spectrum cost (C_{BW}) has been based on data about the historical spectrum auctions in some European markets and India. For example, the mobile operators in Germany have paid around EUR 1.54 per MHz/pop for spectrum in the 800 MHz band and the Swedish operators paid in average EUR 0.68 per MHz/pop in the same band. These prices can be compared with the prices paid for acquiring spectrum resource in the 2.6 GHz band which reach EUR 0.30 per MHz/pop in Sweden, EUR 0.05 in Germany and just EUR 0.01 in the Netherlands [16]. While India the mobile operators have paid a relatively higher fees which range between EUR 1 per MHz/pop to EUR 5 per MHz/pop [17] [18]. The MNOs in Sweden seems be in good position in terms of spectrum holding and paid spectrum fee compared to Indian operators. However, the Swedish mobile operators will need 10 times more spectrum resource at toady cost or lower to provision the targeted mobile broadband service in future in affordable way. On other hand, the Indian mobile operator need 20 to 100 times more spectrum resources; yet at considerable low spectrum price to provision the targeted average data arte in at reasonable cost level in horizon 2020.

V. Conclusion

In this paper, the engineering value of spectrum resources has been studied in different markets; namely in Sweden and India. In this respect, the achieved cost saving ratios as result of using more spectrum resources is considered as the main metric for evaluating the engineering value of spectrum. The main finding in the study thereof indicates that the average spectrum holding has more significant impact in achieving the targeted average data rate per subscriber compared to the densification of the existing infrastructure. However, the anticipated high engineering value of acquiring additional spectrum resources is subject to two factors: 1) if mobile operator is operating in dense regime or not 2) the required investment cost to acquire and to use more spectrum resources. By applying these two factors to the two markets under study; high engineering value can be anticipated for Swedish mobile operators in comparison to the Indian mobile operators. This is due to the low spectrum fees paid by Swedish operators compared to the Indian mobile operators. Hence, the Swedish mobile operators can provision 10 to 100 times more average data rate per subscriber in future at today's cost level; if 10 to 20 times more spectrum resources are acquire at today's spectrum cost. While the provisioning cost of the mobile broadband service in India will be considerable high compared to today cost even if 10 to 20 times more spectrum resources is allocated.

Although the obtained results in this study are subject to the assumptions made and models used, they give general deductive conclusions and open the door for future investigations especially in the research area related to future spectrum management policies. For example, the focal point of regulation of spectrum resources needs to be centric around economically viable use and societal benefits rather than equal allocations between different wireless sectors. In this context, the creation of flexible and efficient use environment of the essential spectrum resources is highly important for the provisioning the targeted future mobile services level at affordable cost especially in dense regime scenarios. Yet, the proposed shifts in spectrum regulations and use will require innovative ways to promote a common use of wireless network infrastructures among mobile network operators and with other wireless sectors (such as the broadcasting sector). In this regards, suitable incentives in the form of flexible regulatory framework, effective resource management schemes and trusted financial compensation models need to be set to assure fair and efficient use of the resources in such common radio access network infrastructure.

VI. References

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