Financing and Pricing Small Cells in Next-Generation Mobile Networks

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Abstract. Small cells technology has also strong potentials for enhancing cell coverage and network capacity of next-generation cellular networks including 5G. From mobile network operators' perspective, small cell deployment will additionally achieve large reduction to the network costs in both fields of capital expenditure and operational expenditure. In this study, we analyze the benefits of small cells' deployment for operators and we list the subscriber incentives for choosing small cells instead of other access types, such as WiFi, for indoor deployment. Furthermore, we provide a financial analysis of the small cell costs for deployment and operation against the corresponding macrocellular costs. We also examine pricing models that could be used to incentivize subscribers and to expedite the small cells' penetration into the market so as to become an economically viable solution. Finally, we present our experimental results demonstrating possible use cases of our cost and pricing models.

Keywords: Small cells, next-generation mobile, 5G, financing, pricing.

1 Introduction

Next-generation mobile technologies, such as 5G, will achieve impressive system's peak data rates and round-trip delays. Nevertheless, the problem of poor connectivity of indoor users is still not expected to be adequately addressed by the existing macrocellular network infrastructure. The solution of condensing the existing mobile network through the deployment of additional macrocells results in high operational and capital expenditures. Thus, the extended use of small cells is the most prominent solution for increasing efficiency in indoor coverage, expanding network capacity without the need of more spectrum resources, and exploiting the capabilities of future mobile networks.

Small cells are short-range, low-cost, low-power base stations connected back to the core network through a broadband Internet connection, such as DSL, cable or a wireless connection. They are based on femtocell (or home base station) technology which has been expanded to include more types of larger cells like

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picocell, metrocell, and microcell [1]. Compared to other techniques for increasing system capacity, such as distributed antenna systems, the key advantage of small cells is that there is very low upfront cost for the mobile network operator. Due to the short transmission and reception ranges of the small cell, this technology improves reception experience and higher capacity for indoor users compared to other deployments and simultaneously the power consumption can be kept in low levels [2].

A significant scientific work on small cell technology has been conducted in the recent years. It initially started from femtocells and later expanding to the more generic concept of small cells. The vast majority of the related scientific literature studies technological issues related with several different areas, such as the spectrum usage, the self-organization, cross-tier and intra-tier interference mitigation, as well as backhauling issues, thus contributing to the expediting evolution of small cell technology. Nevertheless, research on small cells' financing and pricing was triggered from their early appearance, not always in the form of small cells but alternatively over home-deployed femtocells or picocells [3].

The economics of small cells is a field of major importance in this area, since it affects strongly their adoption by both operators and subscribers and therefore has a critical impact on the total success of this technology in terms of commercialization [4]. In the past, operators provided conventional mobile voice and data services through the establishment of a wide area access that was based mainly on macrocellular network infrastructure. However, the introduction of small cell technology poses a new set of challenges to mobile network operators. They certainly should not rely only on the conventional wide area infrastructure to achieve profitable future business, instead they should exploit the business potentials of small cells. Small cells can be a viable service and, furthermore, they can produce high financial benefits for the mobile network operators [5].

In this paper, we present and analyze the benefits of small cells' deployment and we present the mobile network operator's incentives for including small cells in their service offerings as well as the subscriber's incentives for choosing small cells instead of other access types, such as WiFi, for indoor deployment. Furthermore, we address financing and pricing issues of small cells in next-generation mobile networks. The analytical models that we present estimate capital and operational expenditures for the macrocellular and small cell cases. We also provide an analysis for pricing of small cells as an additional mobile service. The proposed pricing models take into consideration the mobile network's utility as well as its valuation from subscriber's point of view. The interesting evaluation results provided by our models can be further utilized in order to incentivize subscribers and to expedite their penetration to the market so as to make small cells a economically viable solution.

The remaining part of this paper is structured as follows: Section 2 presents the key arguments for adopting the small cell technology from both subscriber's and operator's perspective. Section 3 explores the cost issues of small cell technology and describes how the mobile network operator revenues will be generated. Section 4 presents pricing models of small cell service provision that could further used to make it economically viable and profitable for the operators. In Section 5 we make use of our analytical models to obtain numerical results on small cells' financing and pricing under various conditions. Finally, in Section 6 we present our concluding remarks as well as some ideas for future research work in this field.

2 Opting for Small Cells

Small cell technology has several significant benefits for both subscribers and mobile network operators that make it an appealing service and a solution that can compete successfully against the conventional macrocellular coverage as well as solutions based on other standards such as 802.11 series. Table 1 summarizes the most important benefits for both interested parties.

Table 1. Benefits of Small Cells for Subscribers and Operators

Subscribers	**Operators**
1) Increased data rates	1) Lower capital expenditure
2) Lower end-to-end latency	2) Lower operational expenditure
3) Seamless connectivity from indoors to outdoors and vice-versa	3) Offloading traffic in macrocellular infrastructure
4) Increased security	4) Efficient spectrum reuse
5) Ability for closed access	5) Increased network capacity
6) Ability to behave as relay node	6) Lower power consumption
7) Improved indoor coverage and quality	7) Avoidance of macrocell tower installations

From subscriber's point of view, small cell technology brings the base station closer to the mobile terminal and therefore it achieves increased data rates and lower end-to-end latency compared to conventional macrocellular networks. This is a very important feature especially in locations where macrocellular signal strength is poor and mobile connectivity is limited and it can improve not only data services but also mobile voice services. Seamless connectivity from outdoor macrocellular access to indoor small cell is a significant benefit which exploits the mobile flawless handover capabilities. The small cell's ability to behave as a relay node is another important feature that permits the subscriber to expand the macrocellular coverage by using his own equipment. Small cells also offer increased security along with the ability to define a selected group with access permissions. This is an interesting aspect especially when comparing small cells with the conventional WiFi access networks where security and access control is a controversial issue.

From mobile network operator's perspective, small cells permit the expansion of the mobile network in terms of coverage and capacity without any need for investments in new equipment and infrastructures, such as acquisition of new sites, installations of new towers or expansion of the backhaul. At the same time the need for additional operational activities is kept low and other important operational expenses, such as the energy consumption at the access network, are limited. Macrocellular infrastructure is offloaded from a portion of the traffic originating from indoor users, thus increasing the system's capacity. System's capacity is also increased in terms of spectrum, since that the available spectral resources are reused much more frequently.

3 Cost Analysis

In this section we analyze the trade-off between macrocells and small cells in the terms of cost. To this direction we propose two financial models that can be used for the cost estimation, one for the macrocellular case and one for small cells, which are presented below.

3.1 Macrocellular Cost

The macrocellular cost for the mobile network operator is split in two main categories, namely the capital expenditure and the operational expenditure. Typically, both of these cost categories are borne by the operator.

Capital Expenditure. The capital expenditure is the budget that the network operator invests to acquire and deploy new assets that are non-consumable and to deploy them. Typical examples of such types of non-consumable assets are various types of equipment, new sites, such as buildings, and installation of new links. The capital expenditure also includes the budget invested to upgrade existing assets.

Before estimating the capital expenditure for the macrocellular coverage we will estimate the cost for a single evolved Node-B (eNB), which is the macrocellular base station. The estimation of this cost is straight-forward since it consists by the network equipment cost and thus it can be given by the following expression: $C_{eNB} + C_{EPC}$. The amounts C_{eNB} and C_{EPC} are the costs for eNB and Evolved Packet Core (EPC), which is the term used for LTE-A's core network, respectively. At this point, it should be clarified that the C_{eNB} apart from the costs related to the eNB equipment and deployment, it also includes any potential additional costs for the site acquisition and construction as well as any costs related with eNB's backhaul. The amount C_{EPC} includes all the costs related to the core network such as the costs of core packet routers.

In order to have a common reference, the estimation of the capital expenditure for the macrocellular coverage should be done on an annual basis by taking the annual installment payments of the investment into consideration. Therefore we assume a total investment of capital expenditure for N eNBs that is expressed by: $N(C_{eNB}+C_{EPC})$ and that is repaid annually. Generally, the annual installment A for an principal amount P is expressed by:

$$A = \frac{i}{1-(1+i)^{-n}}C \tag{1}$$

where i represents the interest rate and n represents the length of the installment plan in years.

Assuming that all the capital expenditure is made in advance, then the principal amount C equals to the capital expenditure. Thus, the capital expenditure estimation on an annual basis is expressed by the following equation:

$$c_{macro}^{capex} = \frac{i}{1-(1+i)^{-n}}N(C_{eNB}+C_{EPC}) \tag{2}$$

where c_{macro}^{capex} denotes the annual total cost of capital expenditure and N is the number of eNBs.

Operational Expenditure. The operational expenditure is the day-to-day ongoing costs for running the system, for the network's maintenance, as well as for any additional supporting activities. In case the site is leased, then the leasing costs are also included in the operational expenditure. Thus, the annual operational expenditure c_{macro}^{opex} is expressed by the following equation:

$$c_{macro}^{opex} = N(c_{running}+c_{backhaul})$$

where $c_{running}$ denotes the annual total cost for running a single site including the power consumption, in-site and off-site support, as well as in-site and off-site maintenance. For simplicity, maintenance costs are generally considered as linearly proportional to the capital expenditure with a coefficient f_{site}, and all the rest site costs are expressed by the amount c_{site}. Thus, the total running cost can be further expressed as: $Nc_{running} = f_{site}c_{macro}^{capex} + Nc_{site}$. On the other hand, the amount $c_{backhaul}$ expresses the backhaul costs which are generally linearly proportional to the used bandwidth BW with a coefficient f_{BW}.

To summarize, the total operational expenditure per annum can be expressed as follows:

$$\begin{aligned} c_{macro}^{opex} &= f_{site}c_{macro}^{capex} + Nc_{site} + f_{BW}BW \\ &= f_{site}\frac{i}{1-(1+i)^{-n}}N(C_{eNB}+C_{EPC}) + \\ &\quad Nc_{site} + f_{BW}BW \end{aligned} \tag{3}$$

Based on (2) and (3) the total macrocellular cost for the mobile network operator on an annual basis is expressed by the following equation:

$$\begin{aligned} c_{macro} = & \frac{i}{1-(1+i)^{-n}} N(C_{eNB} + C_{EPC}) + \\ & f_{site} \frac{i}{1-(1+i)^{-n}} N(C_{eNB} + C_{EPC}) + \\ & N c_{site} + f_{BW} BW \end{aligned} \tag{4}$$

where i is the interest rate and n is the duration of the installment plan in years.

3.2 Cost for Small Cells

The cost in case of the small cells is split in the same two categories. However, the cost model applied is totally different from that of the macrocellular case.

Capital Expenditure. Before estimating the capital expenditure for the case of small cells, we should clarify that several assumptions can take place prior to the installation of the Home eNB (HeNB). First, the existence of a home broadband connection is a prerequisite since it provides connectivity to the small cell as backhaul. Second, an arrangement should be made on which side (either the operator or the subscriber) will bear the cost of the HeNB equipment and installation. In this study we assume that a broadband connection preexists, so the first cost for backhaul is ignored, whereas the cost for the equipment and the HeNB installation is paid by the subscriber himself. It is obvious that, due to the non-layered network architecture for the small cell case and the absence of intermediate radio access and core network nodes, costs for EPC nodes is also not included. Therefore the only capital expenditure that we consider in this case is the cost for network equipment for interfacing and routing the traffic to/from operator's core network. This cost is denoted by $C_{i/f}$ and represents the total capital expenditure in the case of small cells. Similarly to the macrocellular case, the annual installment for the capital expenditure for this case is expressed as follows:

$$c_{small}^{capex} = \frac{i}{1-(1+i)^{-n}} N C_{i/f} \tag{5}$$

where c_{small}^{capex} denotes the annual total cost of capital expenditure and N is the number of HeNBs.

Operational Expenditure. Similarly to the capital expenditure, the estimation of the operational expenditure for small cells is radically different from the macrocellular case since: (a) site leasing cost does not exist given that the HeNB is installed by the subscriber in his premise, (b) power consumption bears only the subscriber, (c) support and maintenance costs, apart from the networking equipment for interfacing, are not considered since they are negligible and given that the broadband connection is provided by the subscriber himself and all issues address mainly to the subscriber and/or the broadband service provider.

Therefore, similarly to the macrocellular case the operational expenditure is expressed by the following:

$$c_{small}^{opex} = f_{site} \frac{i}{1-(1+i)^{-n}} NC_{i/f} \tag{6}$$

Subsequently, the following equation:

$$c_{small} = (1 + f_{site}) \frac{i}{1-(1+i)^{-n}} NC_{i/f} \tag{7}$$

expresses the total cost for small cell deployment that bears the mobile network operator's side on an annual basis. This expression is based on (5) and (6) and it should be reminded that i is the interest rate and n is the duration of the installment plan in years.

4 Pricing Models

In this section we present the pricing models for small cell service provision, which can be used towards making it an economically viable and profitable solution for the operators. According to [6] two main pricing schemes apply. Both of these schemes follow a fixed rate policy for the service provision since other policies, e.g., separate volume-based charges for the small cell data traffic, would be rather complex to be implemented.

The first main pricing scheme is the one preferred by most operators as reported in [7] and defines a fixed service fee for accessing small cells. This scheme can be applied in various forms, such as monthly service fee for accessing small cells, monthly service fee for hosting small cell equipment, or at once charging, i.e., when the small cell is initially acquired and deployed. There is also the case, although rather rare, that some operators provide free of charge small cell services to all subscribers or to subscribers having a monthly mobile contract above a certain threshold, e.g., the case of Vodafone in Greece and SoftBank in Japan.

In the second pricing scheme, again a fixed service fee is charged to grant access to small cells. Its difference from the previous scheme is that in this case the amount is defined proportionally to the monthly mobile contract that the subscribers have for their conventional macrocell access. Based on the pricing of current commercial deployments described in [6] this pricing scheme is not at all popular among the mobile operators.

Assuming that p_j is the price paid by subscriber j for his selected service plan, then for a population of users U the price vector $p = (p_j : j \in U)$ includes all the charging data for all subscribers. Therefore, the total revenue R of the operator is given by:

$$R = \sum_{j \in U} p_j \tag{8}$$

and is the amount, which the operator wishes to maximize through the applied pricing policy. Since the goal of this paper is to study the financial and pricing aspects of small cells against macrocells we consider two prices, and therefore:

$$p_j \in \{p_m, p_s\}, \forall j \in U$$

where p_m is the price for the basic macrocellular service subscription and p_s is the price that additionally to the macrocellular access, it offers access through a small cell owned by the subscriber. If N_m and N_s is the number of subscriptions of macrocellular and small cell access respectively then the revenue from (8) that the operator wishes to maximize, can also be expressed as:

$$R = N_m p_m + N_s p_s \quad (9)$$

where $N_m + N_s = j$.

In order to decide whether a specific subscriber j selects macrocellular subscription plan only or a subscription plan that combines macrocellular with small cell access, we suppose that the subscribers act in a selfish manner. Therefore the subscribers try to maximize their benefit given the achieved indoor and outdoor throughput as well as the corresponding subscription charges. Other QoS parameters such as delay, delay jitter and loss are ignored for the sake of simplicity. To this direction we define a function that quantifies utility [8] by associating the utility with throughput and price as follows:

$$u_j = \gamma f(T_j) - p_j \quad (10)$$

where the coefficient γ is a subjective measure of user type that expresses how willing to pay the subscriber is for a given throughput T_j. Function f expresses the relation between the level of throughput T_j and an objective measure of throughput's valuation. It is obvious that f should be a concave function, since, for higher throughput levels, changes in the throughput value tend to have lower impact on its valuation. Therefore although the derivative of f is positive, its second derivative should output always negative numbers. On the other hand, throughput T_j depends on various parameters, e.g., user location, user speed, and network conditions.

A user selects a plan including small cell service when $u_s > u_m$ which from (10) means that the necessary condition is that the following expression should be positive:

$$\gamma(f(T_s) - f(T_m)) - p_s + p_m \quad (11)$$

As previously explained function f is concave, but for simplicity's sake we will assume that its output is linear with throughput. The corresponding constant of proportionality is κ and therefore the expression described in (11) gives:

$$\gamma\kappa(T_s - T_m) - p_s + p_m = \gamma\kappa T_{eNB} - p_s + p_m \quad (12)$$

where T_{eNB} is the throughput obtained by the user inside their home using their HeNB. A user that adopts the small cell service obtains T_{eNB} throughput when locating at his home, whereas when locating outside his home it receives the same throughput T_m as a typical user subscribed to the basic macrocellular service. It is important to note that the throughput T_{eNB} can be easily quantified since it depends essentially on the user's broadband connection and any throughput variations due to the user location inside his home are considered negligible.

The value of amount $\gamma\kappa$ depends on the user valuation of the throughput and it is important to specify the threshold value of $\gamma\kappa$ that makes (15) being a positive number.

5 Experimentation

In this section, we make use of the previous analysis in order to investigate the behavior of the financing and pricing models under various conditions. We first explain the methodology followed and then we present the derived results.

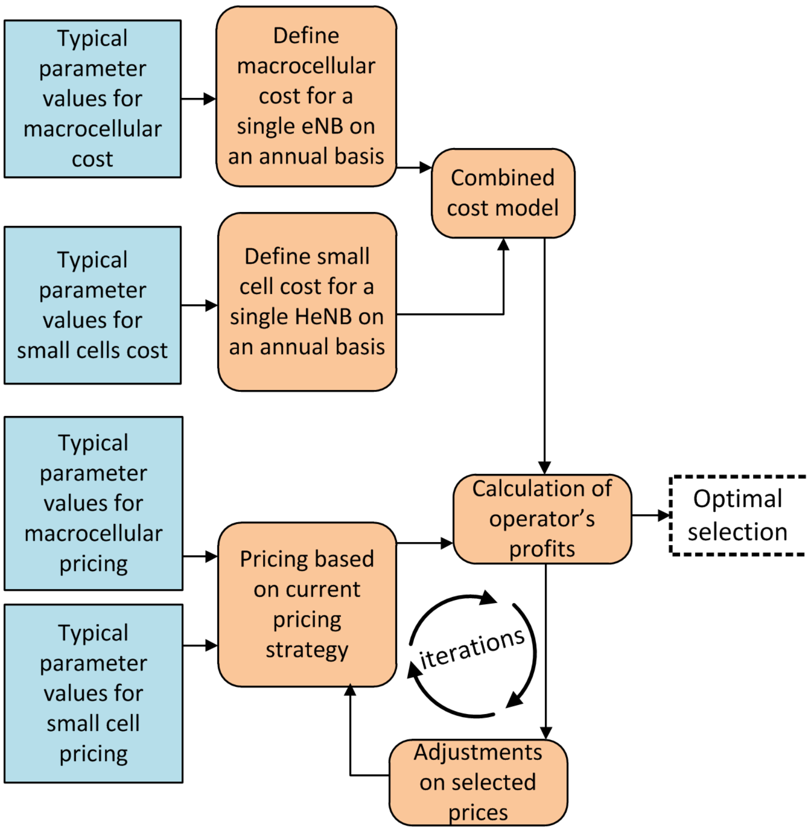

Fig. 1. Methodology followed during experimentation process

5.1 Methodology

Figure 1 illustrates a methodology that is recommended to be followed during the experimentation process. In brief, first we determine the typical values for the parameters used by our analytical models, based on literature review. The next step of the process the application of the models derived from the previous analysis presented in Section 3 and Section 4. The pricing parameters are adjusted through an iterative process in order to eventually lead to the optimal solution.

In order to obtain significant and meaningful results we determined the parameter values based on a review the latest bibliography in the field. The parameters and system variables used, their recommended values as well as a reference to the corresponding study are listed in Table 2 and Table 3.

Table 2. Cost Parameters and System Variables

Parameter	Description	Value
C_{eNB}	Capital cost for eNB	1000 € [9]
C_{EPC}	Core network's capital cost for the deployment of a single eNB	* [9]
i	Annual interest rate	6% [10]
f_{site}	Linear coefficient correlating site maintenance costs with capital expenditure	0.8 [11]
c_{site}	Site costs apart from maintenance cost, e.g., power, in-site and off-site support	3100 € [12]
BW	Backhaul bandwidth for a site's interconnection	10 Gbps [13]
f_{BW}	Linear coefficient correlating site annual backhaul costs with provided bandwidth – expressed in €/Gbps	1170 [14]
n	Duration of installment plan of a site in years	10 yrs [15]
$C_{i/f}$	Capital cost for interfacing a single small cell	110 € [16]

*: Included in the above cost.

Table 2 lists all the system model parameters that are related with financing. These values can be used for the determination of the cost for a single macrocell base station as well as for a single small cell through (4) and (7), respectively.

On the other hand, Table 3 lists all the system model parameters that are related with pricing. These values will be used for the determination of the price that a subscriber is willing to pay for an additional small cell service. To this end, the calculations are based on (15).

$$c_{macro} = 15045 \text{ €} \tag{13}$$

Table 3. Pricing Parameters and System Variables

Parameter	Description	Value
T_{eNB}	Indoor throughput provided by HeNB	15 Mbps [17]
γ	Coefficient correlating throughput with customer's willingness to pay – expressed in €/Mbps	2.8 [18]
κ	Coefficient correlating throughput with its valuation	** [18]
p_m	Price for the basic macrocellular service	295 € [19]
p_s	Price for private small cell access on top of macrocellular one	60 € [20]

**: Included in the above coefficient.

Similarly, deriving from (7) the final annual cost for a single small cell is the following:

$$c_{small} = 27 \text{ €} \tag{14}$$

5.2 Results

The experimental results present indicative usages of the previously presented models. From financing perspective, based on the values presented in Table 2, (4) provides the following cost for a single macrocellular cost for a single base station.

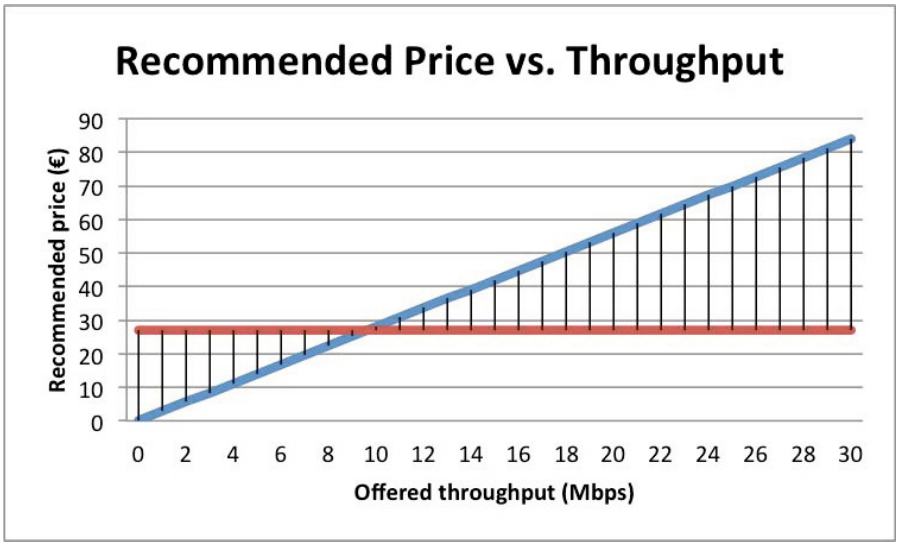

Fig. 2. Maximal price based against offered additional throughput

Based on the values presented in Table 3, (15) provides the following condition that should be true in order for a customer to select small cell service in its subscription plan:

$$p_s < 2.8 * T_{eNB} \tag{15}$$

Figure 2 derives from the above expression and provides an overview of the maximal price against the offered additional throughput. Apart from this relation, for comparison purposes, it illustrates the line from (14) that corresponds to the annual cost for the provision of a single small cell service. It is obvious that the provision of a small cell starts becoming profitable for the operator's side.

Figure 3 visualizes the annual cost for the deployment of a given number of small cells that is listed in the horizontal axis. It also compares this cost with the corresponding total cost for a single macrocellular base station. It is shown that the cost for a single macrocell corresponds to the total annual cost needed from the operator's side for 550 small cells. Additionally, the total profit for the operator is presented. For the calculation of profit the typical value of p_s listed in 3 is used. Please note that this typical value of 60 €implies an average of at least 20 Mbps of additional throughput supported via each one of deployed small cells.

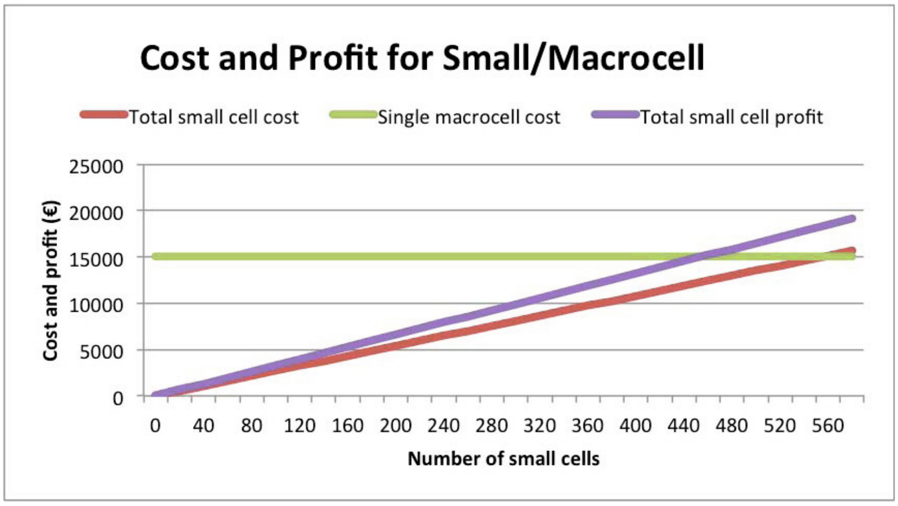

Fig. 3. Small cell cost and profit against macrocellular cost and small cells that are deployed

6 Conclusions and Future Work

In this paper, we analyzed the benefits of small cells' deployment and we presented the mobile network operator's incentives for including small cells in their service offerings as well as the subscriber's incentives for choosing small cells instead of other access types, such as WiFi, for indoor deployment. Furthermore, we addressed financing and pricing issues of small cells in next-generation mobile networks. The analytical models that we presented estimate capital and operational expenditures for the macrocellular and small cell cases. We also provided an analysis for pricing of small cells as an additional mobile service. The proposed pricing models take into consideration the mobile network's utility as well as its valuation from subscriber's point of view. The interesting evaluation results provided by our models can be further utilized in order to incentivize subscribers and to expedite the penetration into the market so as to make small cells a economically viable solution.

Possible future steps following the presented work could extend current analytical models in order to include various access types to small cells. Indicative example is the distinction of open access type and closed access types for HeNB. Another possible future direction could be the organization of the implemented software as a framework that will provide solutions that can be easily utilized, modified or extended by researchers and analysts interested in the topic in order to experiment on similar issues.

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