Comparative Cost-Capacity Analysis of the Advanced Wirelesses Heterogeneous Broadband Networks

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Abstract – **In this paper we develop comparative analysis of the heterogeneous wireless networks in order to determine the most cost effective radio network deployment as a function of excessive user demand of 100 GB per month. Considering various amounts of the spectrum in different microwave bands, we perform the cost modelling of wirelesses heterogeneous networks deployed with the advanced radio access technology like LTE-Advanced or IEEE 802.11ac Wi-Fi standard. The outcome of the cost model is the evaluation of the total investment and discounted cost needed to serve the targeted area. The key contribution is the finding that the small cell solutions like femto cells and Wi-Fi are very cost efficient when new macro base station sites need to be deployed. Also, we outline the significance of the spectrum to what mostly contributes the LTE-Advanced carrier aggregation functionality.**

Keywords – **Wireless Hetnets, Broadband, Comparative cost analysis, LTE-Advanced, IEEE 802.11ac.**

I. Introduction

The forthcoming wireless network has the following hierarchically ranged base stations (BS) sites/cells alongside with wireless local area networks (WLAN/Wi-Fi): macro (MaBS) to cover wider areas, and micro (MiBS), pico (PBS) and femto (FBS). Analysis of MaBS, MiBS and PBS HSPA cells capacity-cost comparisons including IEEE 802.11a, are provided within [1], [2] and [3]. Cost comparisons of LTE with HSPA deployed MaBS networks and FBS solutions are extensively covered within [3] and [4]. Additionally, the cost evaluation of the various deployments of FBS and MaBS for LTE mobile broadband services is outlined in [5].

In this research, we originally propose the comparative cost modeling of utilizing LTE-Advanced (LTE-A) RAT [6] [7], alongside with Wi-Fi standard IEEE 802.11ac [8]. Considering the recent capital and operational cost drivers, we evaluate the capacity-cost efficiency of the wireless heterogeneous networks. As according to [9], more than 80% of the mobile traffic is generated in indoors, we create investment case study of office users considering the wall attenuation, too.

The paper is structured as follows. Sections II and III elaborate BS class specific coverage, capacity and unit cost parameters. Then, we perform investment modeling of various wireless network deployment strategies. In section V, we discuss the findings of the most and less cost-effective deployment scenarios. A conclusion is found in section VI.

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II. Coverage and Capacity Characteristics

According to [10], a BS of class i is characterised by a maximum average throughput or capacity T_{maxi} and cell range r_i. We model the coverage of cell area A_{cell} as follows:

$$A_{cell} = \pi \cdot r_i^2 \qquad (1)$$

Based on [11] the calculation shows that urban cell range varies from 0.6 km at 2.6GHz to 1.4 km at 900 MHz, assuming the Okumura-Hata propagation model [12]. According to [4] and [3] we consider 0.57 km range for MaBS. Based on the elaborations in [2] and [1], we estimate 0.27 for MiBS and 0.1 km range for PBS. FBS cell range in [3] is assumed at 0.050 km and in [13] in range of 0.01 – 0.030 km. According to [14], we model the system capacity, T_{syst}, as follows:

$$T_{syst} = W \cdot N_{site} \cdot N_{cell} \cdot S_{eff} \qquad (2)$$

where W is allocated bandwidth in MHz, N_{site} is the total number of BS sites, N_{cel} number of cells and S_{eff} is the cell average cell spectral efficiency in bps/Hz/cell. Based on [6] and [7] the average spectral efficiency for LTE-A varies from 6.6, 4.2 and 3.8 bit/s/Hz/cell based on the urban environmen [15]. As the interference problems to non-FBS cell occur with the FBS deployment [16], according to [17] we consider FBS deployment in a different frequency band than MaBS. Currently, the LTE FBS are developed with 5, 10 and 15 MHz bandwidth (achieving up to 37, 75 and 112 Mbps, respectively) and available from 8 to 16 users simultaneously [18]. Author in [13], indicates that 4G FBS will utilize the bandwidth of 20 MHz per carrier. We use the indoor average spectral efficiency of 6.6 bps/Hz and 20 MHz of spectrum for FBS with 50m coverage range. According to [19], it is difficult to exceed 50-60% of the nominal bit rate of the underlying physical layer of Wi-Fi. Frame aggregations techniques are used to improve the MAC layer efficiency [20]. According to [21], we consider the IEEE 802.11ac products in the 5 GHz band with 80 MHz and delivering up to 1300 Mbps and up to 30 m coverage range. Table I summarizes the RAN coverage and capacity estimates.

III. Wireless HetNets Cost Modelling

We model cost structure based on the methodology developed in [1] and [5] by limiting to the capital investment to acquire and deploy the RAN (CAPEX), and the costs to operate the RAN (OPEX). According to [22], more accurate model could be obtained by using present values instead of annualizing the CAPEX. In order to calculate the cost per item of type i in present value, according to [2] we use the standard economical method for cumulated discounted cash flows for the whole network life cycle (K years) as follows:

$$\varepsilon_i = \sum_{k=0}^{K-1} \frac{\alpha_{k,i}}{(1+\beta)^k}. \qquad (3)$$

TABLE I
COVERAGE AND CAPACITY PARAMETERS

LTE-A/IEEE 802.11	MaBS	MiBs	PBS	FBS	Wi-Fi
Range (km)	0.57	0.25	0.10	0.05	0.03
Coverage (km²)	1.02	0.19	0.03	0.008	0.003
Bandwidth (MHz)	20	20	20	20	80
Av. Cell SE (bps/Hz)	3.8	3.8	6.6	6.6	16.25
Av. Cell Capac.(Mbps)	76	76	132	132	1300
Av. Site Capac. (Mbps)	228	76	132	132	1300

where $\alpha_{k,i}$ is the sum of expenditures, in terms of CAPEX and OPEX, occurred within year k of an item of type *i* and β is the discount rate. We assume network life cycle of K = 10 years and that all BSs are installed during the first year. According to [5], we use the discounted rate equalized to the cost of capital of β = 12 %. The total network discounted cost normalized per unit of area, can be approximated as follows:

$$C_{TOT} = \varepsilon_M \cdot N_M + \varepsilon_S \cdot N_S \,, \quad (4)$$

where ε_M *is the* total discounted cost of MaBS, ε_S *the* total discounted cost of small BS (or Wi-FI BS) and N_M and N_s is the average number of MaBSs and small BSs. Authors in [3] for 2010 year estimate that cost for deploying a new MaBS site in the urban area is 110 k€ including transmission and that the cost for radio equipment supporting three sectors and 5–20 MHz to 10 k€, yielding to total CAPEX of 120 k€. According to [1] CAPEX for 2-carrier and single carrier MaBS deployment is 20% and 40% lower than 3-carrier MaBS, respectively. Out of [1], we consider the price of a MiBS and PBS station equals 50% and 15%, respectively, of a single-carrier MaBS equipment, with a note that PBS needs 2 k€ for transmission, and MiBS and PBS requires 10 k€ and 2 k€ for the site deployment, respectively. According to [4], on average the deployment of one FBS is around 1 k€. IEEE 802.11ac WLAN access points (AP) for consumers are currently available at prices of around €160 [24]. Nevertheless, for the enterprise solutions there should be used WLAN carrier grade access (see e.g. [25], [26]). Author in [1], outlines that the carrier grade AP is 10 time more expensive than WLAN AP for consumers, and that cost for router and access getaway is 20 k€. Thus, we assume that carrier grade AP supporting IEEE 802.11ac will cost around 1.5 k€, and additional 1k€ should be added per AP, (if control equipment is divided between 20 Aps). Regarding the OPEX, authors in [3] assumes 30 k€ annual cost for the new MaBS site and author of [1] considers 13.4 k€ for the single carrier MaBS by outlining an appropriate ratios of 1.15, 1.29, 0.67, 0.21 and 0.10 related to this cost for the 2-carrier MaBS, 3-carrier MaBS, MiBS, PBS and Wi-Fi BS. Thus, in this paper we assume 20 k€ OPEX for the new 3-carrier MaBS site. According to [3] we assume 10 k€ for the existing site. For the FBS, authors in [3] estimate the annual operational cost as 0.5 k€/BS. The resulting discounted cost calculated according to (3) is shown in Table II.

IV. INVESTMENT CASE STUDY

A. Case Study Description

Based on the per unit cost estimates from Tables I and II in this section we will assess how the total initial investment of varies as a function of the user demand. In particular we consider building of the new office center in the 1 km² urban indoor area through construction of ten 5 floor buildings hosting 10.000 workers. Consequently, we will only the strict indoor solution of small cells represented by FBS alongside with the Wi-Fi (excluding MiBS and PBS). For the macro layer we will consider the CAPEX needed for deployment of three-sector MaBS supporting three frequency carriers, but only single carrier in use.

B. User Demand

Based on [28], the average usage per month of smartphones will rise x 5 times (up to 2.7 GB) by 2018 having 66% from the total traffic and that tablet share will be more than 18%. Following the same ratios, we could draw conclusion that the average usage per month in 2018 will be around 12.2 GB and 6.9 GB for tablets and laptops respectively. Furthermore, [29] predicts an average N. American mobile user to consume 6 GB/month in 2017. Consequently, we will perform the network dimensioning with 44 GB/user/month as moderate and high demand of 110 GB/user/month. We consider that usage is spread out over 8 hours per day, in line with [30]. Table III outlines the conversion of the demand into data rates and capacity.

C. Macro Cellular Deployment Scenario

Assuming the spectral efficiency of 3.8 bit/s/Hz/cell of outdoor LTE-A RAT, the achieved capacity with a single carrier three-sector MaBS site is 114.0 Mbps, 228.0 Mbps and 342.0 Mbps with 10 MHz, 20 MHz and 30 MHz of spectrum, respectively (calculated in line with (2)).

1) Initial Scenario

The requirements on average user data rates during busy hours would be met even at the cell borders with the high broadband demand (~ 1.0 Mbps what is in line with the data rate of 1.0 Mbps as assumed in [11]). Within the initial scenario, we perform the cost-capacity analysis using 20 MHz for the macro-layer in the 2.6 GHz band with the average spectral efficiency of LTE-A RAT. In accordance with [3], for the MaBS site re-use scenario, we estimate the total CAPEX of 20 k€ for existing site (the cost needed to upgrade an existing site is estimated to 10 k€ and the cost for radio equipment supporting three sectors and 5–20 MHz to 10 k€). Accordingly, Table IV summarizes the total invested costs for.

TABLE II
CAPEX, OPEX AND TOTAL COST PER BS CLASS (K€)

BS Class / LTE-A and IEEE 802.11	Initial CAPEX	Annual OPEX	Total discounted cost (10 years)
Macro (1 carrier)	72.9	15.5	152.67
Macro (2 carriers)	96.2	17.8	186.47
Macro (3 carriers)	120.0	20.0	220.15
Micro	35.8	10.4	90.73
Pico	13.5	3.4	31.26
Femto	1.0	0.5	3.72
Wi- Fi	2.5	1.6	12.17

TABLE III
CONVERSION OF DEMAND TO DATA RATES AND CAPACITY

Demand	GB/user/month	Mbps/user	Gbps/km²
Moderate	44.0	0.407	4.0
High	110.0	1.019	10.0

TABLE IV
INVESTMENT & CAPACITY (MACRO - INITIAL)

Macro Initial Scenario – 2.6 GHz		No. Sites	CAPEX (M€)	Capacity (Gbps)
Site type	*Demand*			
New	Moderate	18	2.16	4.1
New	High	44	5.3	10.03
Reuse	Moderate	18	0.36	4.1
Reuse	High	44	0.88	10.03

2) Compensation of Additional Wall Penetration Losses

When trying to compensate for the wall penetration losses, two options are possible [3], [4]: building a denser 2.6 GHz network and deployment using 10 MHz within the 800 MHz band. Authors in [3] calculated that in order to compensate the additional 12 dB of attenuation, 5 time denser network should build at 2.6 GHz band. Cost-capacity outcomes are summarized within the Table V.

3) Carrier Aggregation Scenario

According to [31], carrier aggregation as characteristic of LTE-A RAT, allows combining lower and higher bands (up to 5 carriers and up to 100 MHz). Thus, we originally create one more deployment scenario assuming the aggregation of the both frequency carriers at 800 MHz and 2.6 GHz bands, thus increasing the bandwidth to 30 MHz. Findings are summarized in Table VI.

D. Femto Cell and Wi-Fi Deployments

In line with [3], and explanations for the maximum numbers of users per access point for FBS and Wi-Fi given in Section II above, we consider different options of the user oriented and coverage oriented approaches. Since, the construction of the new office center is green-field we assume no legacy small cell installations within the considered area of 1 km². The Table VII summarizes the cost-capacity figures for the FBS and Wi-Fi deployments.

TABLE V
INVESTMENT & CAPACITY (MACRO -WALL LOSSES COMPENSATION)

Macro Initial Scenario – 0.8 or 2.6 GHz		No. Sites	CAPEX (M€)	Capacity (Gbps)
Site type	*Demand*			
New 0.8 GHz	Mod.	36	4.32	4.1
New 0.8 GHz	High.	88	10.56	10.03
Reuse 0.8 GHz	Mod.	36	0.72	4.1
Reuse 0.8 GHz	High.	88	1.76	10.03
New 5 x 2.6 GHz	Mod.	90	10.8	20.5
New 5 x 2.6 GHz	High.	220	26.4	50.16
Reuse 5 x 2.6 GHz	Mod.	90	1.8	20.5
Reuse 5 x 2.6 GHz	High.	220	4.4	50.16

TABLE VI
INVESTMENT & CAPACITY (MACRO - CARRIER AGGREGATION)

Macro Initial Scenario – 0.8 & 2.6 GHz		No. Sites	CAPEX (M€)	Capacity (Gbps)
Site type	*Demand*			
New	Moderate	12	1.56	4.1
New	High	30	3.9	10.26
Reuse	Moderate	12	0.36	4.1
Reuse	High	30	0.9	10.26

TABLE VII
INVESTMENT & CAPACITY (FBS LTE-A & WI-FI IEEE 802.11AC)

Femto celss & Wi-Fi	No. of sites		CAPEX M€		Capac. (Gbps)	
	FBS	Wi-Fi	FBS	Wi-Fi	FBS	Wi-Fi
4 users / BS	2500	2500	2.5	6.25	330	3250
8 users / BS	1250	1250	1.25	3.13	165	1625
16 users / BS	625	625	0.63	1.56	82.5	812.5
32 users / BS	313	313	0.32	0.78	41.3	406.9
4 BS / floor	200	200	0.2	0.5	26.4	260
8 BS / floor	400	400	0.4	1.0	52.8	520
16 BS / floor	800	800	0.8	2.0	105.6	1040
32 BS / floor	1600	1600	1.6	4.00	211.2	2080

V. FINDINGS DISCUSSION

Fig. 2 outlines the comparison of the investment costs in M € as function of user demand in Gbps, for different network deployment scenarios. It is noticeable that LTE-A MaBS deployment with site re-use and carrier aggregation in place, has the lowest cost for the capacities below 2.0 Gbps. Even LTE-A MaBS deployment with new sites and carrier aggregation in place is more cost effective option compared to the Macro 5xtime denser deployment and site reuse at 2.6 GHz band. Hence, the LTE-A RAT and carrier aggregation functionality form cost perspective could be acceptable MaBS deployment scenario for the new market entrant as well, since with it the new comer will be able to achieve comparable profitability with the existing operators for relatively high demand levels. From other side, deployment with the reuse of the existing MaBS with 10 MHz spectrum in the 800 MHz band causes achieving high demand with tolerable investment of 1,75 M€ due to the superb coverage and penetration performance of the 800 MHz carrier frequency. For the existing mobile operator missing spectrum in the 800 MHz, an option will be to reuse existing sites with 5 time higher density, what is more cost-effective solution than MaBs deployment with new sites in the 800 MHz band what in fact is the less cost efficient option. Thus, we can draw a conclusion that it is very important if new MaBS sites need to be deployed or not. The performances of FBS and Wi-Fi are different. As we already considered those types of indoor deployments are coverage, rather than capacity limited. Their cost depend form the density of BS used. As shown in Fig. 2, for dense network deployments 4 users per FBS/Wi-Fi or 32 FBS/Wi-Fi sites per floor, is less cost-effective option comparing to most of the MaBS deployments unless the user demand is extremely high (above 6.5 Gbps). FBS/Wi-Fi deployments are cost-efficient when single site can support higher number of users (e.g. 32 per site or 4 sites per floor). Thus, for the capacities above 2.0 Gbps, the most cost-effective deployment option is the utilization of 4 FBS per floor.

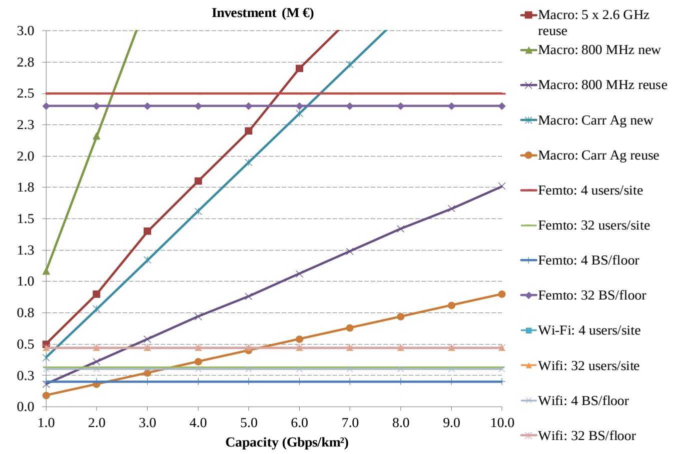

Fig. 1. Comparison of macro and small cells cost as function of the user demand, with the LTE-A and IEEE 802.11ac, respectively

The comparison between FBS and Wi-Fi shows that the FBS solution is more cost effective than Wi-Fi deployment, but from the capacity long-term perspective the better option should be IEEE 802.11ac Wi-Fi deployment due to its superb capacity performance.

VI. Conclusions

We introduce the model for evaluation of the total deployment costs of heterogeneous wireless access networks. For the cellular deployments we use the forthcoming LTE-A RAT and for the WLAN networks we consider the future-proof IEEE 802.11ac standard. Through the investment case study, we have compared the cost-capacity performance for macro and small cell deployments as a function of moderate to very high user demand levels. Findings show that the macro cell deployment scenarios show linear increase with demand. In order to satisfy moderate demand levels, it can be concluded that the re-use of sites have a large impact also when a "denser" macro network is deployed in order to compensate for wall attenuation. The key finding is that use of carrier aggregation functionality of LTE-A will significantly increase the cost-effectiveness of the macrocellular deployment. Thus, with enabling aggregation of the carriers in the band of 800 MHz and of 2.6 GHz on the existing sites we create the most cost-efficient deployment for moderate demand levels. From other side, the indoor deployed femto cell and Wi-Fi solutions (being only coverage limited) are most cost efficient only for the higher to extreme user demands. Results indicate that FBS/Wi-Fi significantly become cost-efficient when single site can support higher number of users, basically due to the very low unit cost compared to the equipment cost of the higher order cellular deployments.

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