Cost-effectiveness Assessment of 5G Systems with Cooperative Radio Resource Sharing

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Abstract — By use of techno-economic analysis of heterogeneous hierarchical cell structures and spectral efficiencies of the forthcoming advanced radio access technologies, this paper proposes various cost-efficient capacity enlargement strategies evaluated through the level of the production cost per transferred data unit and achievable profit margins. For the purpose of maximizing the aggregate performance (capacity or profit), we also assess the cooperative manners of radio resource sharing between mobile network operators, especially in the cases of capacity over-provisioning, when we also determine the principles to provide guaranteed data rates to a particular number of users. The results show that, for heavily loaded office environments, the future 5G pico base stations could be a preferable deployment solution. Also, we confirm that the radio resource management method with dynamic resource allocation can significantly improve the capacity of two comparably loaded operators which share the resources and aim to increase their cost effectiveness.

Keywords — 5G millimeter wave, Cost-effectiveness, EBIT margin, Guaranteed QoS, IEEE 802.11ad, LTE-Advanced, Radio Resource Management, Radio Resource Sharing.

I. INTRODUCTION

THE lack of microwave spectrum to be used by today's and cellular systems from the recent future enabled with radio access technologies (RATs) like 4G LTE Advanced or LTE-A (LTE Release 10 and beyond) [1], forced the recent publications to focus extensively on the coverage and capacity performance of the so called millimeter wave (mmW) systems, utilizing the huge amount of the available spectrum in the mmW bands (30 GHz - 300 GHz) [2]. The capacity and user data rate performances measured in multi-gigabits per second, as outlined in [3]–[6], were our exact motivation, to evaluate the financial ability of new mmW cellular systems (or 5G) to bridge the continuous "revenue gap". This research presents methodologies for the 5G systems mainly through delivering a variety of measurement results that show how e.g. 28, 38 and 73 GHz carriers could be implemented with a bandwidth channel of up to 1 GHz. With this huge

amount of available bandwidth, it is highly expected that capacity overprovisioning will occur often in many 5G based Advanced Wireless Access Heterogeneous Network (AWA-HetNet) layouts to be deployed in the future. Consequently, we analyze possible manners to exploit such overprovision and to propose a solution for an adequate quality of service (QoS) delivered in the form of a guaranteed data rate per individual user. Also, we assess the possibility of further capacity increases by the application of Radio Resource Management (RRM) methods in case of cooperative sharing of the radio resources among two mobile network operators (MNOs).

Capacity-cost comparisons of macro (MaBS), micro (MiBS), pico (PBS) HSPA base station (BS) sites, including IEEE 802.11a/n access points (APs), are provided in [7], [8]. Cost analysis of LTE with HSPA deployed MaBS networks and femto (FBS) solutions are extensively covered in [9], [10]. Additionally, the profitability assessment is provided by various deployments of FBS and MaBS for HSPA and LTE mobile broadband (MBB) services in [11]–[13]. In all studies [7] − [13], authors perform their analysis in the frequency bands higher than 800 MHz band and lower than 2.6 GHz. Various RRM functionalities for cooperative networks were outlined in [14], [15].

In our contribution, we originally present the comparative cost-capacity modeling, production cost calculation and business profitability evaluation of the 5G mmW systems integrated in the future AWA-HetNets together with the 4G LTE-A RAT and advanced Wi-Fi deployment like IEEE 802.11ad [2]. Considering the "up to date" initial and running cost drivers, we deliver results applicable to assess the profit margins of the various outdoor and indoor heavily-loaded AWA-HetNets. Also, we evaluate the suitable radio resource sharing in 5G based AWA-HetNets that will cost-effectively improve the capacity figures due to cooperation of the MNOs aiming to ensure data rate guarantees to end users.

The rest of this article is organized as follows. We describe the analysis approach through elaboration of specific coverage, capacity, and unit cost estimates for various BS and AP classes. Then we model the production cost in order to assess the profit margins of the outdoor deployed beyond 4G and 5G mobile systems. Further, we elaborate the investment case study focusing on the coverage, cost-capacity and profitability performances of the RATs within the newly built office area. Then, in Section VI we assess manners for sharing the radio resources between two MNOs with dynamic data loads in case of capacity overprovisioning with the indoor 5G pico

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base stations. Conclusions are drawn in Section VII.

II. COVERAGE AND CAPACITY MODELING

For modeling purposes, we approximate hexagonal cellular structures with a circle, with radius r, and we assume that subscribers are uniformly distributed within a cell. A BS of class i is characterised by cell range (km) related to coverage (km²). Consequently, we dimension the BS site coverage "A" as the circle area ($A = \pi r^2$). According to [9], [10] and [16] we consider 0.57 km range for the three sectors 4G LTE-A urban MaBS. Based on the elaborations in [3], [6], we estimate 0.1 km range for 3-sector 5G MMW metro bases stations (MetBS), deployed according to the 3GPP Urban Micro (UMi) model [17]. In line with [7], [18] and [19], for the indoor 3-sector 5G MMW PBS we consider a range of 0.02 km. According to [12], we model the aggregated capacity of the system, T_{syst}, as follows:

$$T_{syst} = W \cdot N_{site} \cdot N_{cell} \cdot S_{eff} \qquad (1)$$

where W is an allocated bandwidth in MHz, N_{site} is the total number of BS sites within the system coverage area, N_{cell} is the number of cells per BS site and S_{eff} is the average cell spectral efficiency in bps/Hz/cell. Based on [17] the average spectral efficiency for LTE-A varies from 3.8, 4.2 to 6.6 bps/Hz/cell. In line with [3], [6] for the 5G mmW system we consider an average cell spectral efficiency of 2.83 bps/Hz/cell. We consider LTE-A RAT with bandwidth chunks of 20 MHz, mmW system with 500 MHz [3], [6] and [18]. For Wi-Fi, we consider 50-60% of the nominal bit rate of the underlying physical layer of [20]. Frame aggregations techniques are used to improve the Medium Access Control (MAC) layer efficiency [21]. According to [22], IEEE 802.11ad aims to provide cell capacity of 6756 Mbps using OFDM and 2160 MHz channel bandwidth at 60 GHz unlicensed band, with a coverage range of 10 m.

III. COST DRIVERS ASSESSMENT

We base our cost structure modelling on the methodology developed in [7, 11] by limiting the capital expenditures (CAPEX) and operational expenditures (OPEX) of the radio access network (RAN). The cost per item of type i in present value, according to [8] is based on the standard method for cumulated discounted cash flows represented by summing up the total discounted annual expenditures for the whole network life cycle (K years). The total cost of AWA-HetNets can be modeled as:

$$C_{TOT} = N_i \sum_{i \in \Phi} \sum_{k=0}^{K-1} \frac{\alpha_{k,i}}{(1+\beta)^k} \qquad (2)$$

where $\alpha_{k,i}$ is the sum of expenditures, in terms of CAPEX and OPEX occurred within year k of an BS/AP of type i, β is the discount rate, N_i is the number of BSs/APs that would be required of that kind, and Φ is the set of available BS/AP configurations. In line with [11], we use the weighted average cost of capital (WACC) value of 12.5% for β. We consider 20 k€ for a single carrier 3-sector MaBS costs [7]. We assume 60 k€ for 3-sector 4G MaBS with LTE-A RAT supporting 5 carriers [9].

Consequently, in line with [13] the total CAPEX for MaBS is 110 k€.

TABLE 1: COVERAGE, CAPACITY AND COST ESTIMATES FOR BSs/APs OF DIFFERENT RATs AND CELL TYPES WITH 1 CARRIER

BS Class/ Parameter	MaBS	MetBS	PBS	Wi-Fi AP
RAT	4G LTE-A	5G mmW	5G mmW	IEEE 802.11ad
Environment	Outd.	Outd.	Indo.	Indo.
Range (km)	0.57	0.10	0.02	0.01
Coverage (km²)	1.02	0.03	0.001	0.0003
Sectors	3	3	3	1
Bandwidth (MHz)	20	500	500	2160
Av. Cell SE (bps/Hz)	3.8	2.83	2.83	3.13
Av. Cell Capac. (Mbps)	76	1415	1415	6756
Av. Site Capac. (Mbps)	228	4245	4245	6756
CAPEX (k€)	110	31	19	5
Annual OPEX (k€)	30	19	15	3.5
Tot. discount. cost (k€)	272.5	135.5	106.5	24.8

For the reuse of the existing MaBS in line with [9] we consider 20 k€ related to site upgrade (10 k€) and to the additional radio equipment (10 k€). Regarding the MaBS annual OPEX we consider in total 30 k€. We assume OPEX of 10 k€ per year when an existing site is re-used. We model the related costs of MetBS and PBS, based on MiBS and PBS relations to MaBS from [7]. Regarding the Wi-FI APs, for the enterprise solutions we consider WLAN carrier grade access. The author of [7] outlines that the carrier grade AP is 10 times more expensive than WLAN AP for consumers, and that the cost for router and access getaway is 20 k€.

Due to the very high peak data rate expected with IEEE 802.11ad, we assume that carrier grade access point supporting IEEE 802.11ad will cost around 2.5 k€, and additional 2.5 k€ should be added per AP, assuming that the control equipment is divided between no more than 8 APs. Consequently, Table 1 summarizes the CAPEX, OPEX and total discounted cost estimated for 10 years. The resulting discounted cost structure of future AWA-HetNets is given in Fig. 1, and grouped by radio, site and transmission related costs. As is seen, while radio and site costs dominate for MaBS, transmission costs are also significant for 5G mmW MetBS and 5G mmW PBS sites for optical high-speed backhaul.

IV. DEMAND IMPACT ON PROFITABILITY OF THE FUTURE DENSE URBAN AWA-HETNET

Our primary goal is to relate the total investment costs to the production costs and revenues in order to assess the business profitability of the AWA-HetNet using: a) 4G MaBS with LTE-A RAT and available 40 MHz of bandwidth (10 MHz in 700 MHz, 10 MHz in 800 MHz and 20 MHz in 2.6 GHz band) and b) using the 5G MetBS mmW system in 28 GHz band. According to [23], [24], we consider low, moderate, and high demand levels of year 2020, or: 30, 120 and 500 GB/user/month. Further, we consider the dense urban area of 1.0 km². Today, the capital city of the Philippines, Manila, has the highest population density in the world with around 42,000/km² [25]. Nevertheless, we decide to consider a rather extremely populated area from the future (more than 6 times higher) with 250,000 citizens per km² and mobile

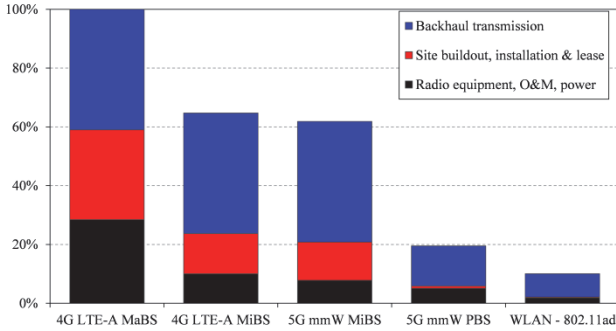penetration rate of 80% in the market with 3 MNOs having equal share.

Fig. 1. BS discounted cost structure of AWA-HetNet.

We represent the generated traffic/capacity over a given area as a function of the MBB population density per MNO ρ (or in our case 66,667 users/km²) as follows [26]:

$$G(t) = \rho \cdot \frac{1}{1024} \cdot 8 \frac{1}{f_{dh}} \cdot \frac{1}{n_d} \cdot \tau(t) \sum_k D_k \cdot s_k \qquad (3)$$

Here, D_k represents the average data demand per month for terminal k (i.e., s_{pc}, s_{tablet}, $s_{s.phone}$), $\tau(t)$ represents a typical daily traffic variation in terms of percentage of the number of active users for a given time t, f_{dh} denotes the number of hours of the day denoted as busy hours when the traffic is intensified and n_d is the number of days of the month in which there is user activity. According to [24], we consider that the usage will be spread throughout 9 hours per day (translating into a busy hour rate of 11.11%) or $f_{dh}= 9$ across 30 days of a month or $n_d = 30$. Further, in combination with the forecasted values, using (3) it is possible to calculate the peak area traffic demand at the busy hour as G [Gbps/km²] $= max_t(G(t))$ under the assumption that all of the subscribers are active during the busy/peak hour (i.e., $\tau_{max} = 100\%$), for the purpose of maximizing the probable cost-capacity estimates of an MNO. Consequently, Table 2 summarizes the area capacity values and the average user data rates, for each of the considered levels of user demand to be satisfied by the AWA-HetNet. The required CAPEX for the considered deployments is presented in the upper part of Table 3. The calculations related to production costs and revenues that yield to the respective results in Table 3 are based on the approach described in [12] used to calculate the production cost per GB. To include the annualized CAPEX as a cost item in the results, the CAPEX for sites and radio equipment are depreciated over 20 and 5 years respectively, with WACC of 12.5%. We assume average monthly revenue per user (ARPU) of 25.0 €. The sum of the annualized CAPEX/GB and overall OPEX/GB (estimated as 45% of the overall revenues based on the assumption that 55% is the EBITDA earnings before interest, taxes, depreciation, and amortization) margin) yields the total production cost per GB. Finally, the profit (or the EBIT) margin is obtained as a ratio of the production cost per GB and revenue per GB. Fig. 2 depicts the resulting profit margin for each of the deployment scenarios considered. It can be seen that the smallest pressure on the profitability comes with a low usage, when the profit margin for all of the four deployments moves

from 52% for the 4G LTE-A MaBS new sites, and up to around 54% for the case of 5G mmW MetBS site reuse. Nevertheless, when maintaining higher demand levels, the profit margin of the MaBS greenfield deployment with 4G LTE-A drastically declines to 6%. In the case of MaBS site reuse with 4G LTE-A, the profit margin is kept rather on the same level until the usage takes off to 500 GB per user and month when it is around 35%. Also, with both deployments with MetBS 5G mmW sites, the profit margin is maintained at the same level of around 54% with no decline, showing the importance of having access with extremely high capacity compensating the coverage limitations.

V. CASE STUDY - COMPLEX OF OFFICE BUILDINGS

A. Case Study Description

In this section, we evaluate the cost-capacity performance of the future 5G MBB network in case when even higher (terabyte – TB) demand levels need to be maintained for the 25,000 indoor office users. Our particular interest is to assess the profit margin of deployments needed to satisfy the 36.0 TB/user/month called the "virtual reality office" demand, as defined in [24]. For that purpose we consider construction of a new office center in the 1.0 km² urban indoor area. The office workers will be spread in the complex of 10, 5-floor buildings. We assess the deployment options with 4G-LTA MaBS sites placed outside the buildings and 5G mmW PBS sites and WLAN IEEE 802.11ad placed inside.

B. Impact of Propagation and Penetration Losses

Due to the increased demand for the 4G-LTA MaBS deployment, we assume that there are available 20 MHz more in the 2.6 GHz band or in total 60 MHz in a downlink. In the deployment scenario with 4G-LTA MaBS we consider the potential increase of the number of 717 sites, needed only to satisfy the increased capacity demand within the considered complex of office buildings. Regarding the 5G mmW MetBS deployment for indoor purposes, the authors of [3], [5] determined that their empirical results for the 100 m distance are mostly close to the Free-space loss mmW model as assumed in the Samsung study [18]. That model on top of the free space propagation assumes a correction factor of 20 dB and could be represented as follows:

$$PL_{FS,dB} = 112.4 + 20\log_{10}(f_c) + 20\log_{10}(d) \qquad (4)$$

where, f_c is the carrier frequency in GHz, and d is the distance in km. For the $f_c = 28$ GHz, and $d = 0.1$ km, we obtain that PL_{FS} is 121.3 dB. According to [4], in order to compensate for the 42.0 dB of additional wall attenuation, out of (4) we calculate that an additional extremely high number of 4,000 mmW MetBS sites have to be deployed.

TABLE 2: TARGETED USER DATA RATES (MBPS) AND ESTIMATED AREA TRAFFIC DEMAND (GBPS/KM²)

Monthly Demand	Usage [GB/user]	User data rate [Mbps]	Area capacity G [Gbps/km²]
Low	30.0	0.25	16.0
Moderate	120.0	1.00	66.0
High	500.0	4.21	274.0

TABLE 3: COST AND PROFITABILITY ANALYSIS OF MACRO AND METRO CELLULAR LAYOUT FOR NEW AND REUSED DEPLOYMENTS, WITH 4G AND 5G RATS, WHEN SATISFYING DENSELY POPULATED URBAN AREA OF 1.0 KM²

Deployment	4G LTE-A (new sites)			4G LTE-A (sites reuse)			5G MetBS (new sites)			5G MetBS (sites reuse)		
GB/user/month (D_k)	30	120	500	30	120	500	30	120	500	30	120	500
Number of BSs	36	145	602	36	145	602	34	34	54	34	34	54
Total CAPEX (M€)	3.24	13.05	54.18	1.44	5.80	6.02	1.56	1.56	2.48	1.16	1.16	1.84
Annualized CAPEX (M€)	0.59	2.37	9.85	0.25	0.98	4.09	0.25	0.25	0.39	0.18	0.18	0.28
Annual. CAPEX / GB (€)	0.0248	0.0247	0.025	0.0102	0.0103	0.0102	0.0103	0.0025	0.00098	0.00729	0.0018	0.0006
ARPU (€)	25	25	25	25	25	25	25	25	25	25	25	25
Revenue (€/GB)	0.83	0.21	0.05	0.83	0.21	0.05	0.83	0.21	0.05	0.83	0.21	0.05
1- EBITDA Margin	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%
OPEX (€/GB)	0.38	0.09	0.02	0.38	0.09	0.02	0.38	0.09	0.02	0.38	0.09	0.02
Production cost / GB (€)	0.3998	0.1185	0.047	0.3852	0.1040	0.0327	0.3853	0.0963	0.0235	0.3823	0.0956	0.0232
EBIT or profit margin	52.0%	43.1%	5.8%	53.8%	50.1%	34.6%	53.8%	53.8%	53.0%	54.1%	54.1%	53.6%

Even more, if we consider the indoor deployment with the 5G mmW PBS we need to exclude out of (4) the 20 dB free space losses, and on top to consider only the inside wall attenuation of W = 13.6 dB in line with [18]. Thus, we obtain that the new d for denser indoor deployment equals 0.02 or it should be needed to deploy in total 797 mmW PBS sites inside the buildings to cover the area of 1 km².

C. Cost-Capacity Analysis and Profitability Evaluation

In case of 4G LTE-A MaBS we consider two deployment options with an aggregation of two carriers (2 x 20 MHz) and with three carriers (3 x 20 MHz). Assuming that the carrier aggregation functionality will be part of the future 5G systems as well, we consider the aggregation of the carriers at 28 GHz, 38 GHz and 73 GHz, each with a bandwidth of 500 MHz. Thus, the capacities are doubled and tripled compared to those outlined in figure in Table 1. Due to coverage limitations in total 3,185 IEEE 802.11ad APs will be needed to cover the area of 1 km² or around 64 per floor. Consequently, Fig. 3 depicts the resulting initial deployment costs of the single RAT network layouts to be deployed in order to satisfy a demand coming from the office areas hosting business users with a demand up to 100,000 GB/user/month. The overall most cost-efficient solution is the use of the 5G mmW PBS new sites with three frequency carriers and 500 MHz bandwidth, whose expenditure curve above 12,000 GB/user/month shows a similar dependence on the capacity increase as the deployment with Wi-Fi IEEE 802.11ad APs.
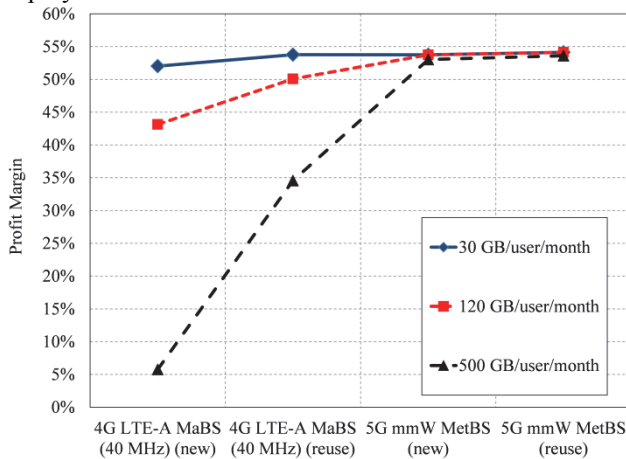
As the area consists mostly of business users, in this case we consider a higher monthly ARPU of 50.0 €. The 4G LTE-A MaBS deployments, seeking massive network rollout, have highly deviating profit margins and can't be considered as an appropriate option for the MNO. In the case of virtual reality office, the only deployments with the positive profit margins are the 5G mmW PBS with three carriers (17%) and Wi-Fi IEEE 802.11ad (16.3%), the first being superior from capacity perspective, and the second besides a high capacity have a very low production cost.

VI. RADIO RESOURCES MANAGEMENT IN CASE OF CAPACITY OVER-PROVISIONING WITH 5G PBSs

Here, we analyze the cases of the potential capacity overprovisioning as a result of the deployments needed to overpass the coverage limitations. Further, we use such results to consider different solutions for the application of Radio Resource Management (RRM) techniques to the cooperating MNOs. For that purpose, we assume that in reality there will be much "regular" demand from the office user with only 10% from the dimensioned 36.0 TB/months. In that case, the average data rate per user equals around 0.1 Gbps and the area capacity reaches the 2,442 Gbps/km². Nevertheless, in case of coverage with the 5G mmW PBS with three carriers we ensure significant overprovisioning or a 4.8 times higher capacity equal to 11,835 Gbps/km².

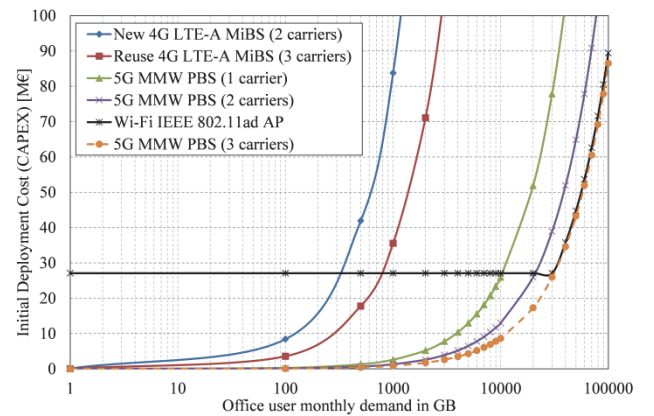Fig. 2. Profit margin based on the annualized CAPEX.

Fig. 3. Infrastructure cost for different RAT systems for office environments (logarithmic scale).

According to [10], this overprovisioning could be exploited by ensuring guaranteed data rates to the users. Hence, based on the tele-traffic theory (the Erlang B loss formula), we could obtain the number of users being served with 1.0 Gbps guaranteed data rate with a certain service probability. For a certain Loss probability (E_{loss}) and a given number of available channels per cells C, we calculate with the use of the "Erlang Loss Formula" [27], the offered traffic flow O in Erlang and by that the average channel utilization $\eta = O/C$. In order to perform this, we assume that 1.0 Gbps is the constant or guaranteed data rate of the user and that it corresponds to 1.0 Erlang of traffic load or it represents a capacity equal to a single channel. Consequently, the average data rate to be provided in the regular office environment of approximately 0.1 Gbps/user corresponds to a traffic load of 0.1 Erlang.

We calculate the number of "best-effort" users N_{best} as a ratio between the number of available channels per cells C and the average data rate per user in Erlang. Finally, the number of users that could be served with a guaranteed data rate of 1.0 Gbps, N_{guar}, with a particular service probability ($SP = 1 - E_{loss}$) is

$$N_{guar} = N_{best} \frac{O_{E_{loss}}}{C} \qquad (5)$$

Now, considering that the cell capacity of the 5G mmW PBS with three carriers is around 14 Gbps (or 14 channels), we could calculate the probability of certain number of users to be served with a guaranteed data rate of 1.0 Gbps, compared to the case when the average data rate is 0.1 Gbps and could be ensured to 140 users.

The capacity of a cellular network weakens with more firm requirements on outage probability. Consequently, Fig. 4 depicts the number of served users with the guaranteed data rate of 1.0 Gbps as a function of the total number of channels C per cell with different average blocking probabilities $E_{loss} \in \{0.05, 0.1, 0.15, 0.2\}$. It can be seen that with 80%, 85%, 90% and 95% of probability 144, 129, 114 and 97 users could be served with a constant data rate of 1.0 Gbps, respectively.

Finally, in line with [14] this approach could be used as an advanced method Radio Resource Management (RRM) functionality between MNOs that aim to share the radio resources or to jointly use a single carrier for the purpose of lowering the investment costs as compared to the case when each MNO uses a dedicated carrier.

Thus, a fixed fraction of the cell capacity can be reserved for each MNO and only one carrier utilized. So, with two MNOs equally sharing the capacity with $C_1 = C_2 = C/2 = 7.0$ channels (equally sized shares) the total capacity is reduced with 23%, 19%, 16% and 14% in case of 5%, 10%, 15% and 20% of loss probability, respectively.

For the purpose of avoiding this fixed RRM solution that will lead to a significant loss in total system capacity or, at the end, could jeopardize the cost efficiency, based on the approach elaborated in [14], we further consider a dynamical prioritization of the MNOs resource shares based on their current load. The prioritization is implemented with priority queuing in the admission control, where each connection belonging to one MNO should receive a priority calculated based on MNO's current load relative to their agreed minimum capacity.

Next, we briefly describe the analytics of the so called "method with non-preemptive priority queuing in admission control" that is originally introduced in [14]. So, according to [14], we consider the standard Poisson traffic model according to which the total offered load per MNO i is denoted Oi, and is defined as

$$O_i = \lambda_i T. \qquad (6)$$

where λ_i is the average arrival rate of new connections for MNO i and T is the average duration per connection. The total offered load in our case can be given by $O = O_1 + O_2$. The total number of channels per cell C is still modeled as constant, or each MNO has a prioritized access to a total number of $C_1 = C_2 = C/2$. Further, the priority level of each MNO, Pi, is defined as

$$P_i = C_i / L_i. \qquad (7)$$

so that MNOs with a load L_i lower than the agreed minimum capacity Ci receives a higher priority. How effective the differentiation in blocking probability is depends on the probability that enough resources are released before the maximum allowed waiting time T_{max} is reached, after what a connection should be blocked. The performance can be evaluated by observing the MNO specific blocking probability B_i that should be below a certain threshold B_{max} until the operator reaches its agreed minimum capacity C_i. or:

$$B_i \leq B_{max} \quad \text{for } O_i < C_i. \qquad (8)$$

A connection is admitted if there is at least one channel available, that is if

$$\sum_{i=1}^{N} L_i < C. \qquad (9)$$

and blocked if no channel is released before the maximum allowed waiting time T_{max} is exceeded. In our case, we consider the total number of channels is $C = 14$ for the data service, allowed queuing time $T_{max} = 15s$, average connection time is 12 s, and data rate is 1.0 Gbps. Table 4 summarizes the simulation results for the achieved gain relative to the case with a fixed allocation of 7 data channels.
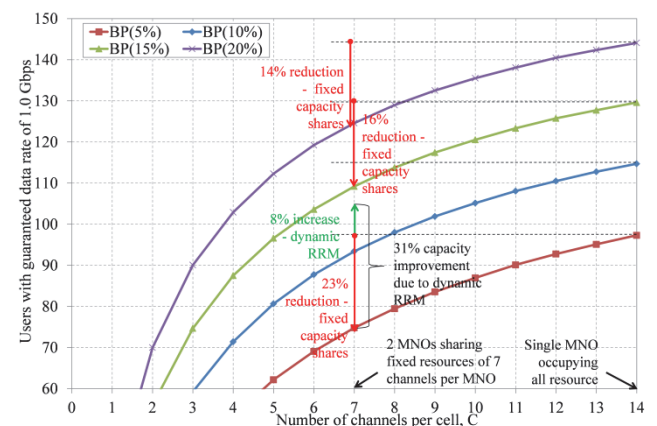

Fig. 4. Served users with the guaranteed data rate of 1.0 Gbps in case of indoor 5G mmW PBS, with highlighted capacity changes due to particular RRM used.

TABLE 4: CAPACITY GAIN RELATIVE TO A FIXED CHANNEL
ALLOCATION WITH 5% BLOCKING PROBABILITY

Parameter	Value			
O_2 [Erl] / O_1 [Erl]	700%	220%	85%	20%
Capacity gain	-64%	-11%	40%	125%

The blocking probability of the first MNO B_1 is referred to the tolerable value of B_{max} = 5% and for different levels of load for the other MNO (O_2) compared to the load of the evaluated MNO (O_1). It can be seen that when the load is high for the second MNO O_2 compared to the load of MNO O_1, there is a loss in capacity as compared to the reference case with 7 dedicated channels. However, with a moderate load for the second MNO, for example reaching 85% of the load of the evaluated MNO O_1, there is an increase of the carrier load of the MNO O_1 for around 40% in comparison to its load in case of the fixed channel reservation. Consequently, the average channel utilization η will be increased from 0.53 to 0.75, what value compared to the channel utilization in case of single MNO brings even a capacity increase of 8%. Even more, if we compare this result with the result of the comparison between the channels utilizations of single only and two MNOs in case of fixed channel reservation, the result shows a significant capacity improvement of 31%. This is depicted in Fig.4, where one can see the capacity gain with the "RRM method with priority queuing in admission control" in comparison to a fixed RRM share.

VII. CONCLUSION

This paper discusses a theoretical and instructive techno-economic model developed to evaluate the cost-effectiveness of the future AWA-HetNets. The results show that the future 5G mmW system can be a way for MNOs to ensure their profit sustainable on a high level (more than 50% profit margins). A comparable deployment option with more than 15% profit margin comes with the Wi-Fi IEEE 802.11ad, too. Also, we introduce a method to be exploited in a way to differentiate the users requiring for a guaranteed data rate of 1.0 Gbps in case of 5G pico base stations deployments. Further, we analyze the cooperative resource sharing. We show that despite the RRM approach that could provide a perfect fair sharing of the available capacity (with fixed capacity shares), the cost MNOs have to pay for the fair capacity allocation is utmost likely higher than the value added due to the capacity reduction. For that purpose, we extend the analysis to the use of the resource sharing method with the use of RRM with priority queuing that dynamically adjusts to the load of the MNOs. The results show satisfactory capacity improvements of 31% when two MNOs handle comparable loads in comparison to the situation of RRM approach assuring fixed resource shares.

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