Cost Revenue Trade-off for the 5G NR Small Cell Network in the Sub-6 GHz Operating Band

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***Abstract*—5G Radio Access Network (RAN) dis-aggregation has opened up opportunities toward the 2nd phase of 5G. 3GPP and Telecom industries have defined backhaul, fronthaul, and mid-haul transport interfaces, as well as functional splits to incorporate network flexibility and openness. In this work, splits 6 and 7 (7.2) of 3GPP are addressed for implementing sub-6 GHz future wireless mobile communication networks. The 5G-air-simulator has been considered to simulate New Radio 2.6 GHz, 3.5 GHz, and 5.62 GHz frequency bands by using Video (VI) and Video plus Best-Effort (VI+BE) with the Proportional Fair (PF) packet scheduler. The split 6 is ideal for small cell deployment, while split 7, (mainly sub-split 7.2) requires high fiber capacity, which may increase the price of the fronthaul. In the simulations, we have considered a uniform user distribution and reuse pattern three. By assuming a set of cost parameters and a given price for the traffic, we have analysed the cost/revenue trade-off of outdoor pico/micro cells, while comparing the implementation of functional splits 6 and 7 with scenarios without splitting. It is shown that, for all bands, for cell radii up to 500-600 m the split 6 and 7 provides higher revenue and profit compared to the case without splitting (with slight advantage for split 7).**

***Index Terms*—Functional Splits, 5G Air Simulator, Goodput, PLR, Cost/Revenue Trade-off.**

I. Introduction

In the era of digitization and industrial expansion, Industry 4.0 is thriving on the foundation of the connected society and emerging technologies. The evolving industrial age will significantly advance the value-chain automation, security, and business models [1]. World wide mobile operators are in the deployment phase of the Fifth Generation (5G) networks, which have become critical for the smart industries. 5G New Radio (NR) offers higher bandwidth, lower latency, and a higher device density than the existing mobile network.

The 5G NR was introduced by 3GPP in Release 15 [2], followed by enhancements in succeeding Releases. The recent Release 17 [3] NR's non-terrestrial deployments, improved uplink control and data channel design, and support for Frequency Range 2 (FR2) and 60 GHz unlicensed bands. It has also specified improved massive MIMO multi-transmission and reception points (TRP) and multi-beam operation. In 2015, the International Telecommunication Union (ITU)- Radiocommunication Sector published requirements for 5G networks and services [4]. It defined enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and massive Machine Type Communications (mMTC) as the main trends of 5G. ITU-R, 3GPP, ETSI and other organizations have published the specifications and recommendations for 5G and beyond networks tackling growing requirements, architectural needs, and various radio access technologies like, 5G NR, LTE-M and NB-IoT, driving the design of next-generation RAN [5]. During the 41st meeting, ITU-R study group 5 (Working Party 5D, WP 5D, [6]) discussed the ongoing initiatives and research towards "IMT Vision 2030 and Beyond" [7].

5G Radio Access Network (RAN) dis-aggregation has opened up new opportunities. 3GPP and Telecom industries have defined transport interfaces (backhaul, fronthaul, and mid-haul) and functional splits to incorporate network flexibility and openness. Network Functions Virtualization (NFV) enabled the Mobile Network Operators (MNOs) to implement fully–centralized Cloud–RAN (C–RAN) and dis-aggregated RAN architectures. 3GPP's Release 15 [2] defines a flexible 5G RAN architecture with the gNodeB split into the Central Unit (CU), Distributed Unit (DU), and Radio Unit (RU), as shown in Fig. 1. CU and DU are used to implement different split options. The high-level functions are distributed over the mid-haul (CU and DU). By 2026, it is expected to have around 2.5 billion 5G voice users [8], experiencing high-end interactive calling features. Endless opportunities have opened up new business and investment models for providers and users. The transforming technologies will evolve and develop hand-in-hand with significant revenue opportunities. Companies are significantly making investments in 5G and beyond technologies. The critical attributes for the telecommunication sector are the cost/revenue trade-off and underlying profit. There is disruptive cross-sector competition among the MNOs and vendors. The MNOs expected to implement business models to support 5G services to serve the goal of ubiquitous connectivity.

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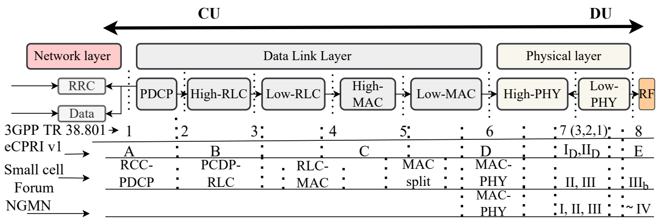


Fig. 1: Different Functional Splits proposed by 3GPP [9].

Different services, such as emerging applications, factory automation, and autonomous driving, has stringent latency, throughput and reliability requirements. These requirements open new challenges to network management and architecture design. It makes it tough for the operators to trade and select the proper set of splitting. Functional splitting is the critical enabler of a future wireless network. It allows the coordination of performance features such as latency, throughput and cost. To analyze the optimal split option for higher throughput with low latency and minimum cost, this study analyzed split 6 and 7, with Video (VI) and VI+Best Effort (BE) applications. Suggested the best option for minimum cost without affecting system performance. A similar study on functional splits is presented in [10], [11].

This paper aims to understand the cost/revenue trade-off of a 5G pico/micro cellular scenario by using the 5G-air-simulator [12]. The output of the simulations enables to analyze the Packet Loss Ratio (PLR), average delay, goodput and number of supported users for the 2.6 GHz, 3.5 GHz and 5.62 GHz frequency bands. Supported goodput curves for video (VI) and VI+best effort(BE) are used as an input to the cost/benefit analysis whilst comparing functional split 6 and 7 with cases where functional splitting is not considered at all.

The remaining of the paper is organized as follows. Section II briefly discusses the 3GPP functional splitting. Section III presents the motivation and goals, followed by Section IV's scenario and approach description. Section V discusses the achieved results, followed by the analysis of the cost/revenue trade-off, and profit analysis in Section VI. Finally, in Section VII, the main conclusions of this work are drawn.

II. 3GPP Functional Splitting

3GPP has defined functional splitting while suggesting eight split options and extending them to further sub-splitting possibilities [9]. DUs' functions reside near the user and will be placed at the antenna side. The functions in the CU will benefit from centralization processes and the high processing power within data centers. The functional splits proposed by 3GPP and enhanced Common Public Radio Interface (eCPRI), Small cell forum, and Next Generation Mobile Networks (NGMN) [13], are presented in Fig. 1.

Authors in [14] have proposed different functional splitting in higher-layer to enhance the CPRI requirements, while the authors in [15] proposed to shift the radio processing functions from the BBU to the Remote Radio Head (RRH) to decrease the load on the fronthaul.

Split 7 has further sub-splits, sub-divided into 7.1, 7.2, and 7.3. That include RRH functionalities like Inverse Fast Fourier Transform (IFFT), resource mapping, precoding, and cyclic prefix addition that reduces the load on the fronthaul. The lower physical layer (in some cases higher physical layer) is processed at the RRH, while the other functions are processed at the edge of the cloud. 3GPP suggests that the MAC-PHY split (6) between the Media Access Control (MAC) and Physical Layer (PHY) shifts the RF, PHY and other functionalities to the RRH.

Split one is the split between the Radio Resource Control (RRC) and the Packet Data Convergence Protocol (PDCP), while split two is the split between the PDCP and Radio Link Control (RLC). In split 2, the RRC and PDCP are kept in the BBU, and all the other processing functionalities (RLC, MAC, PHY, and RF) are processed at the RRH.

Split option 1 to option 6 are well-thought-out with higher layer splitting suggestion [16]. The eCPRI specification defines the split options with different nomenclatures like A, B, C, D, ID, IID and E [16], [17] eCPRI considered the splits ID, IID, within the PHY layer corresponding to the option 7. It also considers the split E, corresponding to option eight, in line with the usual functional split used by CPRI, where the D splits are taken as split 6.

III. Scenario and Approach

In the scope of this paper, the cost/revenue trade-off of splits 6 and 7 (two options that encourage the centralization concept) are analyzed in the small cell environment. Based on our assumptions for a micro cellular scenario, we explored whether split 6 is the best solution for small cell deployments [18], as it can improve not only the data rate but also reduce the cost of the network and power consumption.

We have simulated a scenario with nineteen cells in the 5G-air-simulator [12] and considered the Proportional-Fair (PF) packet scheduler. The central cell is the cell of interest and only communicates with User Equipment (UE). The UEs are deployed inside the central cell, and the remaining 18 cells are only interfering cells. The procedure for deploying users with a uniform distribution in the 5G-air simulator [12]. The deployed users are limited to the central cell and can not leave the central cell to nearby cells, as shown in Fig. 2. Reuse pattern three (k = 3) is considered. From this analysis, we can determine the number of supported users and goodput.

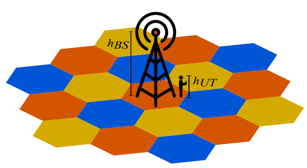


Fig. 2: Micro cell with interfaces with one cell having users while others are interfering.

We have considered functional split 6 and split 7 (7.2) [9]. The split 6 is ideal for small cell deployment, while split

TABLE I: Simulations Parameters

Frequency Band [GHz]	2.6	3.5	5.62
NR operating band	n7	n78	n46
Numerology μ	0		
Frame duration [ms]	10		
Subcarrier spacing	15 KHz		
Number of subframes per radio frame	10		
Number of slots per subframe	1		
Number of symbols per slot	14		
Number of slots	10		
Transmitter power small cells [dBm]	40	42.2478	46.6953
Transmitter power UT [dBm]	23		
Number of BS	19		
Reutilization	3		
Bandwidth per tier [MHz]	20		
Cell radius [m]	1000		
Effective UT height [m]	1.5		
Effective BS height [m]	10		
Scheduler	PF		
Applications	VI and VI+BE		
Video bit rate [Mb/s]	3.1		
Number of simulations	50		
Simulation duration [s]	46		
Flows duration [s]	40		

7 (mainly sub split 7.2) requires high fibre capacity, which increases the fronthaul price.

For this simulations, we have compared the 5G radio performance of the NR operating bands (2.6 GHz, 3.5 GHz and 5.62 GHz) for Video (VI) and Video plus Best-Effort (VI+BE) by considering the Proportional Fair (PF) packet scheduler. Assumptions are as follows:

- For video only, we have considered a video trace of the simulator [19].
- For the best effort flows, we have considered infinite buffer sources [19].
- PF schedules the traffic of a user when its instantaneous channel quality is relatively high compared to its own average channel condition over time. The PF scheduler is used as a typical way to find a trade-off between requirements of fairness and spectral efficiency. It is effective in reducing variations in user bit rates with little average bit rate degradation, as long as user average values of SINR are fairly uniform [20].

The simulation parameters are presented in Tab. I. Numerology zero with a sub-carrier spacing of 15 kHz is considered, with ten subframes in a single frame. Each single frame duration is 10 ms, while each sub-frame is 1 ms. Every sub frame further contains one slot which carries 14 symbols. The height of the base station is settled to h_{Bs} = 10 m in the simulated scenario. The cell radius varies from 15 m to 1000 m. The transmission time interval (TTI) is 1 ms. The actual time for the simulations is 46 s, and the period of each one of the video streams is 40 s. The results are obtained by getting an average of 50 simulations.

IV. Simulation Results

The scenario from Fig. 2 has been simulated to obtain the packet loss ratio. As shown in Fig. 3, for the longest values of the cell radius, the minimum value for PLR occurs at 5.62 GHz for long cell radius, but PLR = 2% occurs at the same number of users as for the shortest cell radius at lower frequency bands. The PLR at 2.6 GHz is less than 3.5 GHz and 5.62 GHz. For example, if we consider the case of R = 0.04 km then, in Fig. 3 a), the 2.6 GHz band supports almost five users with minimum PLR compared to others. With the same cell radius, in Fig. 3 b), the PLR of the 3.5 GHz band goes above 2% with five users. At the 5.62 GHz band, the PLR crosses the 2% target PLR for the same cell radius, and six users are supported. At 2.6 GHz, almost 9 users are supported (with PLR less than 2%) for the same cell radius. For cell radius of 1 km, the 5.62 GHz frequency band performs better than the 2.6 GHz and 3.5 GHz bands.

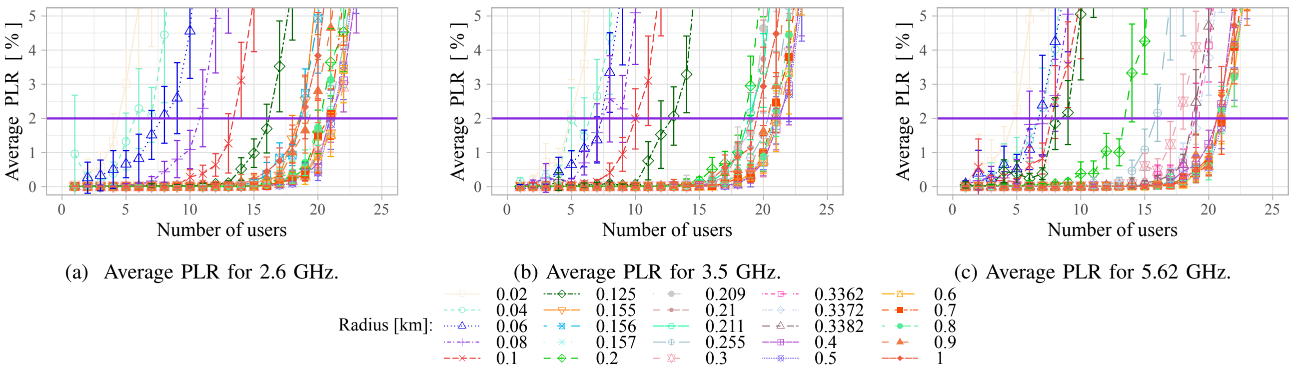
Fig. 4 shows the average goodput as a function of R, varying from from 0.015 to 1 km. To obtain these results with a given set of parameters, we have first performed the simulation for Video (VI) and then for Video Plus Best Effort (VI+BE). It is demonstrated that, for the shortest cell radii, at 2.6 GHz, VI+BE provides a higher supported goodput than in the 2.6 GHz VI case. Besides, with VI+BE, in comparison to the 5.62 GHz and 3.5 GHz frequency bands, the 2.6 GHz frequency band performance is better. Furthermore, the 3.5 GHz VI+BE and VI case serve better than the 5.62 GHz VI+BE and VI cases, respectively, for a shorter cell radius range (up to circa 400 m). For the shortest cell radii, the 5.62 GHz band achieves higher PLRs (above 2%). On the other hand, for values of cell radius beyond 0.6 km, the 5.62 GHz band provides higher goodput than the 2.6 and 3.5 GHz bands.

Fig. 5 shows the number of supported users as a function of R. It clearly shows that the 2.6 GHz band supports a higher number of users for the shortest cell radius. As shown in Fig. 5, for cell radii up to 400 m, the 2.6 GHz band supports 21 users (its maximum value among the bands). For Rs beyond 700 m, the 5.62 GHz supports a higher number of users.

V. Revenue, Cost and Profit analysis

The economics of mobile radio networks includes the perspectives of subscribers, network operators, service providers, regulators, and equipment suppliers. The main concern of the subscribers, regulators and vendors are discussed in [21]. The main goal of network operators and services providers is to increase his company profits. As a result, their objective is to determine the best configuration that would maximize his anticipated net profits [21]. Availability of affordable prices of services (e.g., television and streaming) is the concern of the service providers. In the cellular planning process, the operator goals are to identify the best operating point that will maximize projected revenues. The technology to be employed, the size of the cell, and the number of channels to use in each cell are a few examples of the key aspects that need to be addressed [22], [23], [24].

To analyse the cost/revenue trade-off without and with functional splits (6 and 7), the models from [25] and [24] have been considered. The revenues per cell, $R_v/cell$[€], can be achieved as a function of the throughput per Base Station



(a) Average PLR for 2.6 GHz. (b) Average PLR for 3.5 GHz. (c) Average PLR for 5.62 GHz.

Fig. 3: Average PLR for 2.6 GHz, 3.5 GHz,and 5.62 GHz with number of supported users.

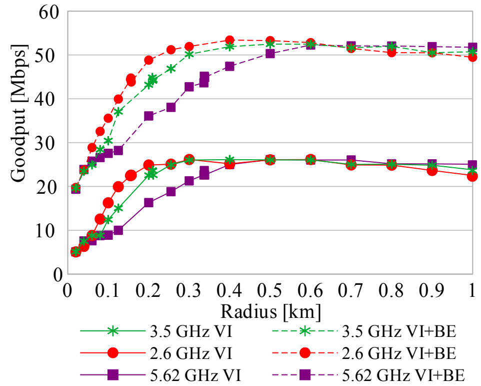


Fig. 4: Goodput as a function of R, for the 2.6 GHz, 3.5 GHz, and 5.62 GHz bands, with VI and VI+BE traffic.

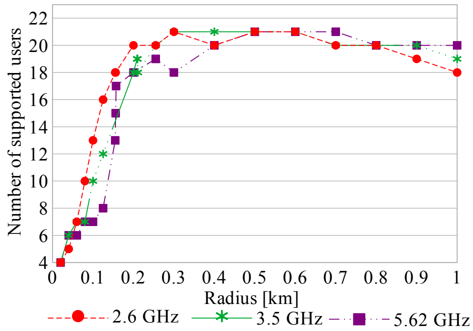


Fig. 5: Number of supported users as a function of R.

(BS), $R_{(b-sup)}$[kbps], and the revenue of a channel with a data rate $R_{b[\text{kbps}]}$, $R_{R_b[€}$ [€/min], and T_{bh} corresponding the equivalent duration of busy hours per day [23], R_v/cell[€] can be obtained by following equation. The revenue per coverage zone (hexagonal cell) can be calculated as follows:

$$(Rv)_{\text{cov-zone}} = \frac{N_{\text{hex.}}\, R_{(b-sup)equiv} \cdot T_{bh} \cdot R_{R_b[€/\min]}}{R_{b-ch[kbps]}} \quad (1)$$

where $R_{R_b[e/\min]}$ is the revenue of a channel with data rate $R_{b[\text{kbps}]}$, N_{hex/km^2} is the number of hexagonal areas, $R_{b-ch[\text{kbps}]}$ is the channel's data rate and T_{bh} represents busy hours per day and the number of busy days per year. With the above equation, one can obtain the revenue per unit area by considering the revenue per cell and the number of cells per unit of area.

TABLE II: Values for costs without splitting & with splits 6/7.

Parameters	Without splitting	Split 6	Split 7
BS_{cost}	100%	25%	20%
C_{BS} [€] (RRH+BBU)	5700	–	–
$C_{BBUplusFH}$ [€]	2000 (FH)	2000+1067	2000+1333
C_{RRH} [€]	5700 (BS)	1425	1140
C_{BH}[€]	2000 (3000 € for fiber instead of FSO)		
C_{inst} [€]	200		
R_{b-ch} [kb/s]	144		
$C_{M\&O}$ [€]	200		
C_{Bh}[€/km^2]	3000		
C_{fi} [€/km^2]	13.01 (2.6 GHz)		
C_{fi} [€/km^2]	10.58 (3.5 GHz)		
C_{fi} [€/km^2]	0 (5.62 GHz)		
Auction [€]	6000000 (2.6 GHz)		
Auction [€]	4880000 (3.5 GHz)		
T_{bh}	86400		
C_b without splitting [€]	2380		
C_b for Split 6 [€]	1281.4		
C_b for Split 7 [€]	1338.4		
R_{Rb} [€/min]	0.0004		
Total area of Portugal [km^2]	92212		
Project duration [years]	5		

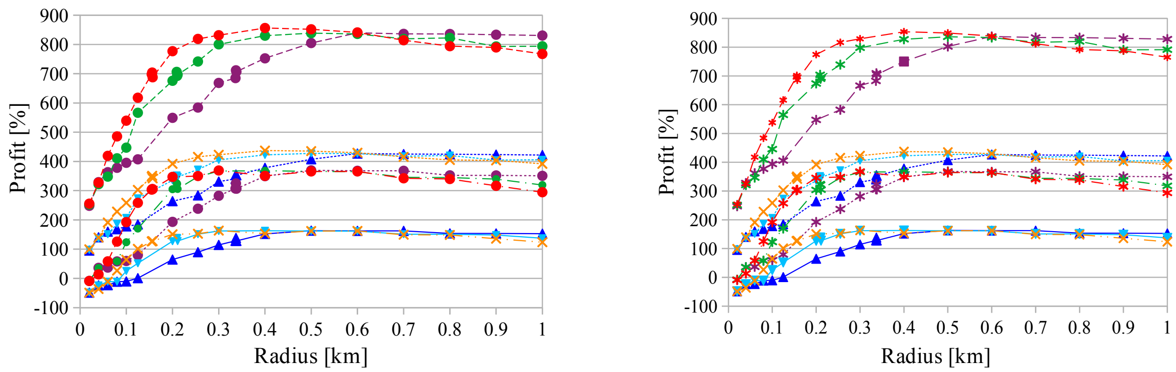
The analysis proposed in this work considers that the costs will be evaluated on an annual basis. Parameters are presented in Tab. II. First, we define the price per unit of area as follows:

$$C_{[€/km^2]} = C_{fi[€/km^2]} + C_b \cdot N_{hex/km^2} \quad (2)$$

where $C_{fi[€/km2]}$ represents the fixed terms of the costs, C_b is the cost per BS given by equation 3 and N_{hex/km^2} is the number of hexagonal coverage zones per unit of area and is given by equation (4):

$$C_b = \frac{C_{RRH} + C_{Bh} + C_{BBUplusFH} + C_{\text{inst}}}{N_{year}} + C_{M\&O} \quad (3)$$

$$N_{hex/km^2} = \frac{2}{3 \cdot \sqrt{3} \cdot R^2} \quad (4)$$



(a) Comparison between split 7 and "without" splitting.

(b) Comparison between split 6 and "without" splitting.

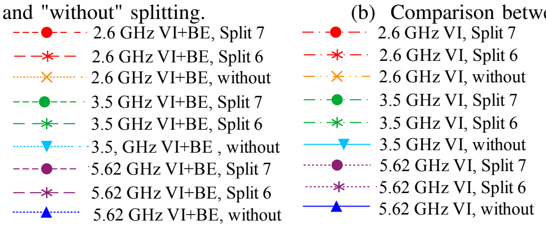


Fig. 6: Profit in percentage terms "without" splitting and functional splits 6, 7, considering VI or VI+BE traffic.

where C_{RRH} is the cost of the RRH (in the case 'without splitting' RRH+BBU are together), C_{Bh} is the cost of the Backhaul, C_{BBU+FH} is the cost of the BBU plus fronthaul, C_{inst} is the installation cost of the BS and $C_{M\&O}$ is the maintenance and operation cost, as presented in Tab. II. One-to-many BBU/RRH mapping is assumed (6 RRHs per BBU)

We did our analysis based in the main land of Portugal, and we assumed the licence value from the auction of ANACOM for the 3.5 GHz band, which is 36.90 million €, while for the 2.6 GHz band it is 6 million €, and 0 € for the 5.62 GHz unlicensed band, for 20 MHz bandwidth, for k = 3 (in the auction 30 lots of 10 MHz, were considered). By dividing this cost per square kilometre, by the number of years for the project, one obtains an annual fixed cost of 79.38 $€/\mathrm{km}^2$ for the 3.5 GHz bands [10], as follows:

$$C_{fi[€/km^2]} = \frac{\frac{\text{licence price}}{\text{country area}}}{N_{\text{year}}} \tag{5}$$

N_{year} represents the project's lifetime.

The profit is presented in percentage terms in Fig. 6 for split 7 and for split 6 , one can get these results by considering equations 1 and 5 to get profit equation 6. The profit is given by equation (6):

$$P_{ft[€/km^2]=} R_v - C \tag{6}$$

while the net revenue gives the profit in percentage, i.e., the difference between the revenue and cost, normalized by the cost, as follows, equation (7):

$$P_{ft[\%]} = \frac{R_{v[€/km^2]} - C_{[€/km^2]}}{C_{[€/km^2]}} \tag{7}$$

The revenue per km of VI and VI+BE can be calculated according to equation (8):

$$R_{V[€/km^2]} = N_{hex[km^2]*} \frac{R_{b-\mathrm{sup}[kbps]}\cdot 60\cdot 6\cdot 240 \cdot R_{R_{b[€/min]}}}{R_{b-ch[kbps]}} \tag{8}$$

Revenues are considered on an annual basis, where we thought 6 busy hours per day, 240 busy days per year [22], and the price of a 3.1 Mbps channel per minute (corresponding to the price of $\approx$ 1MB), [€/min] = 0.0004, which is very low as compared to the value considered in [26].

Although the curves with the cost and revenue per square kilometer as a function of the cell radius are not represented, we can mention that the VI+BE traffic gives the best revenue per square kilometre compared to VI. The 2.6 GHz revenue is higher than the 3.5 GHz and 5.62 GHz bands in for both VI and VI+BE cases. Moreover, the cost for 2.6 GHz, 3.5 GHz and 5.62 GHz are compared with the values of the revenue. The cost for the 2.6 GHz band is lower than at 3.5 GHz (and higher than at the 5.62 GHz unlicensed band, as the price for this band is zero).

For all of the frequencies bands, the cost when functional splits are considered is lower than in the case where there is no functional splitting ("without" scenario).

With split option 6, results for the cost and revenue indicate that the cost for the 2.6 GHz frequency band is lower than for the 3.5 GHz band. Besides, the 5.62 GHz band has the lowest cost of all considered bands. For VI and VI+BE traffic, split option 6 and 7 revenues at 2.6 GHz are higher than in the 3.5 GHz and 5.62 GHz bands.

Fig. 6 shows the profit in percentage terms. It is observed that the profit of the split 7 (sub-split option 7.2 has been adopted), case with VI+BE, is higher than the one for split 7, case with VI, shown in Fig. 6a. For example, if we look at the 2.6 GHz frequency band, in the scenario of split 7 shown in Fig. 6a, in the case of VI+BE traffic, one gets the most elevated peak of the supported goodput (corresponding to PLR of 2%). Profit reaches above 800% for $R = 400$ m. The 2.6 GHz frequency band performs better than all other bands.

Fig. 6b shows the split 6 profit in percentage terms for the three frequency bands. Again, it is found that VI+BE traffic performs better than supporting VI alone. Besides, the 2.6 GHz frequency band performance is also the best one. For a cell radius of 400 m, the peak profit achieves above 800% with slight advantage to split the sub-split option 7.2. The decision between the advantage of split 6 versus split 7 is very sensitive to the cost parameters, namely the costs for the BBU, FH and RRH.

The best profit occurs for the VI+BE traffic at all frequency bands. For the shorter radius (400 m) 5.62 GHz frequency band profit is lower than 2.6 and 5.62 GHz band for both split options.

VI. Conclusions

The paper provided the analysis of the cost/revenue trade-off by considering deployments without and with functional splitting (split 6 and 7). The 2.6 GHz, 3.5 GHz and 5.62 GHz frequency bands were considered and simulations were performed for users either using VI or VI+BE traffic. Based on those results, the goodput, the number of supported users and PLR are evaluated for three frequency bands. Revenues depends on the supported average goodput, obtained for the PLR target of 2% (average delay was never the limiting factor). With VI+BE the 2.6 GHz frequency band supports higher goodput in the range of shorter cell radius (pico cells). For longer cell radii, the 5.62 GHz GHz provides higher goodput. The 3.5 GHz band provides higher average supported goodput than the 5.62 GHz band for shorter cell radii (small cells). For the shortest cell radius, the best is to select the 2.6 GHz frequency band to support a higher number of users and higher average goodput. Overall, the best revenues are achievable with split 6 and 7 for the 2.6 GHz band with VI+BE traffic, with lower cost and higher profitability. It is shown that, for cell radii up to 300-600 m, the split 6 and 7 provides higher profit compared to the case without splits for all frequency bands (slight advantage for split 7), with maximum achievable profit for cell radius of circa 400 m (at 2.6 GHz).

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