1. Introduction

The data rates used by mobile network subscribers have been augmented the last few years either via excessive social media usage or video-streams. Thus, most traffic is exchanged in video form online. The next decade almost 7-10 devices per person will be connected via the Internet. The Internet of Things (IoT) is a technology contributing in this direction, as simplistic domestic devices such as cookers, fridges etc. are going to be connected in the Internet and will offer the chance of remote managing of these appliances via applications in mobile phones.

Nowadays, mobile subscribers require augmented demands in terms of mobile service experience, which require large network resources. Users are not extremely content by network's efficiency and ask for better services in lower prices. They also require coverage on the most remote places, such as high mountains, beaches etc. as social media are a huge part of the everyday life and thus, users want to stay connected as much as possible.

On the other hand, providers' investments need to reciprocate, as it is a well-known fact that large amounts of money were spent for the deployment of Long Term Evolution-Advanced (LTE-A) networks and the expected or desired profit is yet to be received. As a result, companies may not show willingness to invest money in novel deployments, technologies or equipment.

Moreover, all this mentioned traffic augmentation will gradually contribute to the fact that the network resources will not suffice for the users as well as the network. Therefore, operators should find a way to augment Bandwidth (BW) and coverage without highly augmenting the network's cost. A possible answer to this issue could be to virtualize BW using the Network Function Virtualization (NFV) technique and find inexpensive and easy ways to use more. NFVs are useful for creating virtual resources and offer equipment in the whole network without the high costs of hardware. It solely consists of software and wherever it is used in the network, it could replace hardware, with all the well-known benefits, such as lower capital, maintenance, investment, equipment, operational costs etc. Studies in the field have shown that NFVs reduce the network costs from 20% to 80% depending on the specific part that is substituted.

What is more, technologies that are able to reallocate the network resources or use it more efficiently or introduce novel evolved concepts, such as small cells, Software Defined Networks (SDN), IoT, Massive Multiple Input

Multiple Output (Massive MIMO), Cloud computing, Cognitive Radio (CR) will be highly exploited as they appear to be (Akyildiz et al., 2016) the 5G key enablers.

An ideal solution could be to use the Milimeter Wave (mmWave) frequency bands. mmWave covers the frequencies between 30-300 GHz that are not highly used, nowadays, as a result, they could be used for mobile networks. In these frequencies, there is some astronomy equipment that emits, but the band is rather underused. Current mobile network technologies emit in 3.7-24 GHz (Wang et al., 2015). Thus, using the larger frequencies could be a possible solution, could contribute in offering the desired spectrum and could enhance the network performance.

What is more, it becomes obvious that mmWave will star in 5G networks and it is of extreme significance that the mmWave is analyzed in a techno-economic way, so that the most expensive and financially advantageous factors are pinpointed. On the one hand, all strong points should be fully exploited so that they enhance the networks' conditions and the weaknesses should be reduced, so that the highest profits are offered to both end users, providers and operators. Thus, it is of paramount significance that mmWave technology is analyzed from a techno-economic point of view and the most cost bearing parameters are pinpointed.

In this paper, the mmWave is analyzed in a technical and financial point of view. Models are developed and several scenarios are analyzed. Several experiments are conducted using a Sensitivity Analysis (SA), namely checking several parameter prices are used and it is indicated whether or not a specific network parameter is useful or is not cost-effective for the network and therefore, several actions should be taken, such as specific research etc. that should reduce these network parameters. The specific models that are developed in (Bouras et al, 2014) are updated in this paper, several parameters are opted and checked. Conclusions concerning the mmWave are deduced and future research activity is proposed.

The remaining part of this paper is structured as follows: Section 2 indicates previous research in the field. Section 3 presents the architectures of the developed deployments used for the economic analysis. In Section 4 the cost models for the different proposals are described. In Section 5 the parameters used for the experimental process are opted and justified. In Section 6 the experiments are conduced and the corresponding results are analyzed. Finally, in Section 7 the paper is concluded and in Section 8 ideas for future research in the field are listed.

2.Related Work

In this section, the most substantial related works in the field, concerning the mmWave are summarized. 5G networks are closer than ever, because it is going to be widely put into practice in 2020. Today's technologies, such as: LTE-A, bandwidth allocation algorithms do not adequately cover the future network demands and requirements. Several novel technologies could update conventional concepts and thus, traditional approaches should be widely introduced. The SDN, NFV, IoT, mmWave, Cognitive Radio (CR), Ultra-dense deployments are of the 5G key enablers and should be developed and implemented individually or in combination so that they cover future network demands (Akyildiz et al., 2016).

In (Qiao,2016) the methods needed for memory allocation and re-usage are analyzed. In this context, the video streams are transmitted properly. In general, network coverage is enhanced drastically. mmWave technology faces a great amount of environmental and weather conditions that deteriorate the communication between devices and the signals' condition, such as rain, air, particles, snow, etc. Several multiplexing strategies are considered in order to ensure the parameter identifiability, derive JRC statistical bounds and numerically demonstrate superior performance of proposed low-complexity JRC super-resolution algorithms over conventional two-dimensional fast Fourier transform/MUltiple SIgnal Classification (Dokhanch,2019). Another issue raised by mmWave is that the beam training should be implemented in a way so that beams direct their signals together. Novel approaches have been proposed, such as a large enough neural network can predict mmWave beams and blockages with success probabilities that can be made arbitrarily close to one (Alrabeiah, 2020). What is more, there is a proposal for a hybrid precoder and combiner is suggested in (Li et al, 2019).

On the other hand, mmWave is capable of offering a great networking speed and therefore, data rates longer than the Gigabits per second are managed What is more, the use of infrastructure mounted sensors (which will be part of future smart cities) to aid establishing and maintaining mmWave vehicular communication links could be exploited (Ali, 2020). Moreover, mmWave includes great assets, such as: Digital Beamforming, which enhances the overall performance of the system and as a result, the users' Quality of Experience (QoE). The low resolution digital BeamForming architectures can be a power-efficient alternative to analog or hybrid BeamForming for both transmitters and receivers at millimeter-wave (Dutta,2020). It is also claimed that by using the authors solution (Attiah et al., 2019) the mmWave could offer QoE at a low cost.

What is more, several fundamental questions remain open and unanswered. Different approaches need to be found so that the today's existing antennas will be reused (Niu, 2015), (Sulyman, 2014), how the bandwidth is reallocated and also how will the unlicensed bands be managed and distributed for the mmWave technology (Maccartney, 2015). There is a CNN framework that does not require knowledge of steering vectors of array responses and it provides higher performance in capacity compared with the conventional greedy- and optimization-based algorithms (Elbir, 2019).

In (Niu, 2015) the most substantial advantages and disadvantages of mmWave communications are presented. The proposed architecture (Kalfas et al., 2019) leverages optical transceivers, optical add/drop multiplexers and optical beamforming integrated photonics towards a Digital Signal Processing analog fronthaul. The functional administration of the fronthaul infrastructure is achieved by means of a packetized Medium Transparent Dynamic Bandwidth Allocation protocol. Preliminary results show that the protocol can facilitate Gb/s-enabled data transport while abiding to the 5G low-latency KPIs in various network traffic conditions.

(Dong et al., 2019) demonstrates that deep CNN can efficiently exploit channel correlation to improve the estimation performance for mmWave massive MIMO systems. Big data analytics for mobile networks consist a substantial network of key figures, such as wide variety, high volume, real time velocity and huge value. What is more, in the (Hong-Ning Dai, et al., 2019) a big data analytics approach consists of four stages: Data Acquisition, Data processing, Data Storage and Data Analytics is proposed.

Licensed Shared Access (LSA) and Citizens Broadband Radio Services (CBRS) consist the latest trends in spectrum sharing management especially in the United States of America (USA). They also play a substantial role when it comes to the C-band and its wide adoption. In Europe, these approaches are less popular since, European bodies lack of enforcing capabilities. (Massaro et al., 2020)

The 5G networks will create a new mobile business ecosystem. Several regulations are introduced to address technical improvements and operations especially for the higher frequency bands. What is more, a local micro licensing model is proposed for the spectrum allocation in 5G networks. (Matinmikko et al., 2018)

3. Alternative Deployments

In this section, the two different deployments explained in the paper, are analyzed. Two different models one for the mmWave and one for the MidBand spectrum are presented below.

3.1 Milimeter Wave (mmWave)

Telecommunication networks nowadays use the midband frequencies to cover the mobile network demands. Until recently these frequencies were used to cover the video streams and social media usage etc. In the future, they are not going to meet the excessive demands, as more and more BW will be needed for video-streaming, new emerging services will connect all the different kinds of domestic or entertainment or other devices. Thus, mmWave (30-300GHz) frequencies could consist a possible alternative. Today, this band is used for space and satellite transmission and is really underutilized, so it could support mobile network transmissions.

This band includes important advantages, but also has several drawbacks. On the one hand, a Line of Sight (LoS) transmission is necessary for emitting strong signals. mmWave is able to successfully transmit the signal without the need for repetition at a distance of 220m. However, there is also a possibility of signal transmission without LoS, by making the signal reflect in several buildings or other solid surfaces, but the signals in this case seriously degrade. A lot of devices (repeaters, transceivers etc.) should be installed in the premises so that the transmissions are successful (Sulyman, 2014). The most remarkable benefits that mmWave offer are (Wang et al., 2015):

- High antenna gains
- Low output power
- Augmented data rates
- Quick licensing policy
- Cost effectiveness

On the other hand, mmWave includes a great deal of drawbacks, such as: (Wang et al., 2015)

- Atmospheric problems
- Weather conditions
- Dust & small particles

- Foliage

3.2 MidBand Spectrum (MBS)

Networks nowadays transmit into the MidBand Spectrum, namely 1-6GHz. Although, these frequencies are of low cost and are relatively effective, they seem to be saturated and will be unable to cover future requirements. Figure 1 presents the Ultra-dense concept, namely there are several microcells within a macrocell and several small cells within a microcell. What is more, within each smaller cell, the available frequencies are reallocated and thus, this deployment helps augmenting the network coverage.

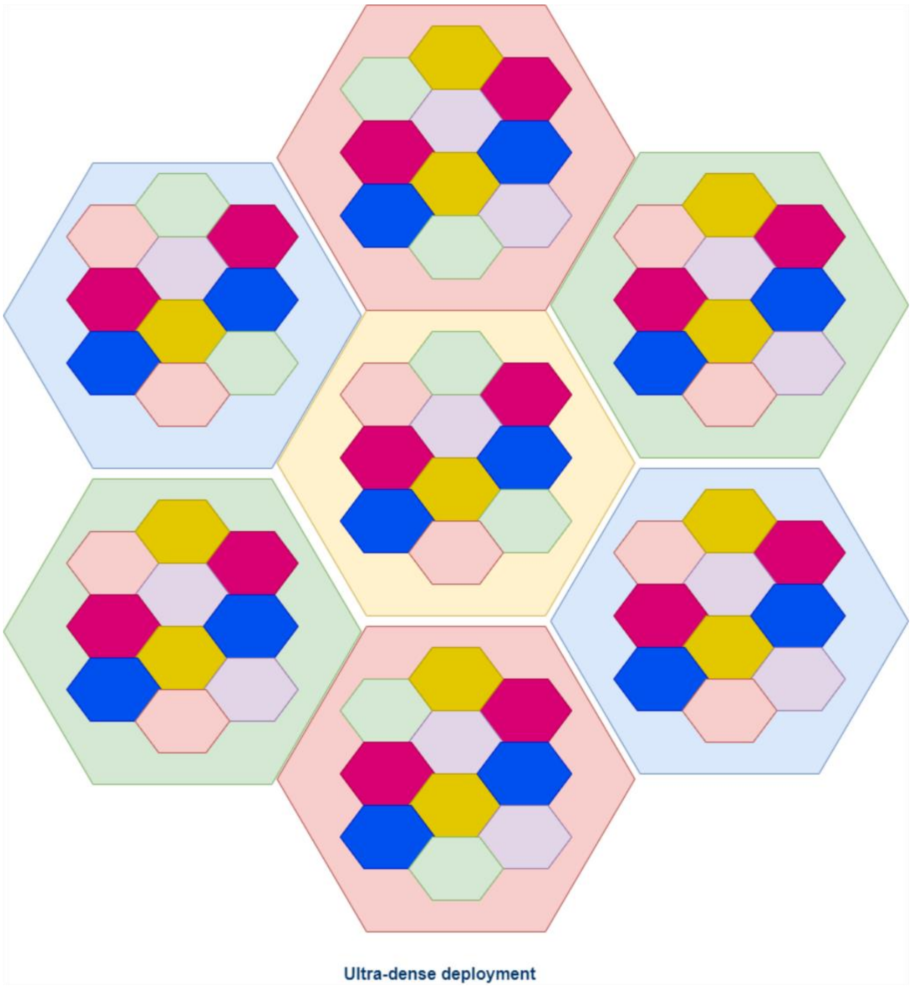


Figure 1: The Ultra-dense architectural concept.

Ultra-density is a very substantial concept, as it offers:

- Increased throughput
- Improved coverage
- Better handovers
- Lower power consumption

3.3 Comparison

Figure 1 summarizes the basic characteristics of each frequency band. The frequency bands are compared and contrasted in terms of cost efficiency, problems and issues appearing, high performance and coverage, the possibility of using this spectrum using different technologies in combination creating heterogeneous architectures, the frequencies that are included and the level of adoption of this band nowadays.

Frequency / Factor	mmWave	Midband
Cost	Higher costs	Lower costs
Issues	Weather issues	not enough coverage for 5G
High performance		
High coverage		
Possibility for heterogeneous deployments		
BW	1-30GHz	30-300GHz
Adoption	Possibly in 5G/ Astronautics	Band of previous generations

Figure 2: Comparison of the basic network characteristics of the mmWave and MidBand spectrum.

A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is a technique that helps indicating how each specific issue deriving from external or internal factors could be either helpful or harmful to achieve a goal or promote a product. Strengths and Opportunities are both helpful deriving from internal and external factors respectively. Weaknesses and Threats are both harmful and derive from internal and external factors respectively. A SWOT analysis lists the Strengths, Weaknesses, Opportunities and Threats that are pinpointed by adopting these frequencies. Although both appear to offer several strong points especially in terms of performance and efficiency, they face several weaknesses, such as high costs or weather conditions. What is more, providers (external factor) may have distrust to invest in novel solutions, since the money from previous ones have not reciprocated yet, but on the other hand 5G's advent is imminent and companies will avoid remaining with obsolete equipment.

Table 2: The SWOT analysis of the mmWave in 5G networks.

Origin	**Helpful**	**Harmful**
Internal	**Strengths**	**Weaknesses**
	● High percentage of data transfer ● Fast and low-cost licensing ● Highly efficient ● Unused frequencies ● Congestion of today's used frequencies	● Atmospheric conditions ● Weather Conditions ● Small particles ● High cost of mmWave leasing ● Trees and other natural environment factors
External	**Opportunities**	**Threats**
	● 5G's advent ● Conventional Technologies do not meet 5G demands therefore, research in the field becomes a necessity ● Novel services and products are linked to 5G ● 5G networks will be very different than today's network as complex, combinatorial and heterogeneous solutions will be needed	● Investing in new products/equipment etc. is needed by the providers ● Distrust by providers about the trade-off between investment vs profit ● Distrust by providers about the trade-off efficiency/advantages vs expenses ● Former investments (of LTE-A) technologies may have not full reciprocated yet

mmWave is helpful as 5G data could be transferred within this band. The licensing of mmWave could be fast and low-cost. This band is efficient and most of this spectrum has yet to be used. On the other hand, all the weather, atmospheric and nature conditions should be taken into consideration for succeeding in providing better network performance and avoiding the signal degradation. 5G is closer than ever and conventional technologies do not meet the network demands. New services and products are linked to 5G networks. The mmWave and the telecommunication networks in general are threatened by the need for novel technologies and the disbelief of providers for new investing plans.

4. Cost Analysis

In this section, the developed cost models are analyzed and explained. Two different models, namely one for the macrocell and one for the small cell scenario, are presented. In these models, the costs are split in two different categories, namely the Capital (CAPEX) and the Operational Expenses (OPEX). The CAPEX cost bears the owner of the equipment and therefore, is paid during the investing period. These types of costs include: the necessary equipment, site expenditures etc. OPEX includes all the costs concerning the network's operating, managing and coordinating activities. The Total Cost of Ownership (TCO) is the sum of CAPEX and OPEX, it includes all the costs of the parameters and factors of the network.

The CAPEX is calculated as a loan and as a result, in order to calculate these costs, the following equation is needed:

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

A is the investment, i is the interest rate, n is the installment plan and C is the initial expenditure for a specific network component. This equation is used for calculating and provisioning the amounts that should be paid in the future. In this paper, this amount include money that need to be paid in advance and are obtained in a loan form, such as CAPEX etc.

4.1 Macrocells

The macrocells are analyzed. The CAPEX and the OPEX are divided into two different categories. They are both paid by the network operator.

4.1.1 CAPEX

For the CAPEX costs, it is considered that an evolved NodeB (eNB) is introduced in the architecture. eNB includes all the network equipment and the expenses for the network deployment. Several other added costs should be paid, such as costs for the core network or the packet routing. Packet routing costs are called Evolved Packet Core (EPC). Following the previous analysis, it seems that the total costs for one single eNB is considered as $C_{eNB}+C_{EPC}$.

All these different costs are paid in a yearly basis and this money consist an investment. Thus, the Equation 1 is needed for the calculation of this amount. Therefore, there are N BSs and are used to calculate the CAPEX of the macrocellular models (C_{MACRO}^{CAPEX}) and are analyzed below:

$$C_{MACRO}^{CAPEX} = \frac{i}{1-(1+i)^{(-n)}} N(C_{eNB} + C_{EPC}) \ (2)$$

4.1.2 OPEX

The macrocells include several costs for managing and operating activities. There are several different costs that are included in the macrocellular case. If C_{run} is the cost for the system's running, which also includes power consumption, operational activities and costs for obtaining the bandwidth. What is more, it also includes all the costs for the running of the single site. Any other cost is considered in f_{st} and C_{site}. The first cost is linearly proportional to the CAPEX. In the assumed architecture, an amount of N_{eNB} eNBs are included in order to cover the network requirements.

Thus, the OPEX is: $NC_{run} = f_{st}C_{MACRO}{}^{CAPEX} + N_{eNB}C_{site}$. The Bandwidth (BW) is an amount, that is leased and it is given by the coefficient f_{BW}. This amount is leased by a specific official authority and it is obtained by the network operator.

Therefore, the OPEX for the Macrocells is represented by C_{MACRO}^{OPEX} and is given by the following:

$$C_{MACRO}^{OPEX} = f_{st}C_{MACRO}^{CAPEX} + N_{eNB}C_{site} + f_{BW}BW f_{st}\frac{i}{1-(1+i)^{(-n)}} N_{eNB}(C_{eNB} + C_{EPC}) + NC_{site} + +f_{BW}BW \ (3)$$

4.1.3 TCO

The sum of the CAPEX and OPEX develop the TCO of the Macrocells (C_{MACRO}^{TCO}) and the following equation is formed:

$$\begin{aligned} C_{MACRO}^{TCO} &= C_{MACRO}^{CAPEX} + C_{MACRO}^{OPEX} = (f_{st} + 1)C_{MACRO}^{CAPEX} + N_{eNB}C_{site} + f_{BW}BW = \\ &= (f_{st} + 1)\frac{i}{1-(1+i)^{(-n)}} N_{eNB}(C_{eNB} + C_{EPC}) + N_{eNB}C_{site} + f_{BW}BW \qquad (4) \end{aligned}$$

4.2 Small cells

In this subsection, the model considered for the small cell case is developed based on (Bouras et al, 2014). The small cell facilitate a small infrastructure, such as a small office or a house, thus, it is understood that both the CAPEX and OPEX costs are paid by the owner of the small cell e.g. (femtocell, picocell, attocell, etc.).

4.2.1 CAPEX

The small cell consists of the Home evolved NodeB (HeNB), which includes all the different costs for equipping and deploying the network. Although, the small cells do not induce remarkable costs, they induce costs for routing and interfacing activities, which could be given by the $C_{i/f}$, which is considered to be an investment paid during the investment period and therefore, the amount of money needed annually should be considered using the Equation 1. In the infrastructure, there is an amount of N_{HeNB} HeNBs and as a result, the CAPEX for the small cells (C_{small}^{CAPEX}) is given by the following equation:

$$C_{small}^{CAPEX} = \frac{i}{1-(1+i)^{(-n)}} N_{HeNB}\left(C_{i/f}\right) \quad (5)$$

Broadband network connection exists in most building nowadays and it is paid by the users. This cost is ignored in this analysis. After all, in accordance to the European Union, in European countries the digital expansion and broadband connection exists in the 98% of the households since 2016.

4.2.2 OPEX

The macrocells do not include many costs and expenditures as all the different types of activities needed, bear the small cell owner. The activities for the operation, the day to day management and coordination, power consumption are considered to be linearly proportional to the CAPEX multiplied with a factor f_{st}. Besides, most costs such as broadband connection, power consumption, siting costs are paid for the building no matter the existence of the small cell or not.

The C_{small}^{OPEX} is considered to be as follows:

$$C_{small}^{OPEX} = f_{st} C_{small}^{CAPEX} f_{st} \frac{i}{1-(1+i)^{(-n)}} N_{HeNB} C_{i/f} \quad (6)$$

4.2.3 TCO

The sum of the CAPEX and OPEX develops the TCO of the Small cells (C_{small}^{TCO}) and the following equation is formed:

$$C_{small}^{TCO} = C_{small}^{CAPEX} + C_{small}^{OPEX} = (f_{st}+1) C_{small}^{CAPEX} = (f_{st}+1) \frac{i}{1-(1+i)^{(-n)}} N_{HeNB} C_{i/f} \quad (7)$$

5. Pricing Parameters

In this paper, the parameters are presented. In Table 3 all the different useful parameters are gathered. Several variables and network parameters are opted by past research activities (Bouras et al, 2014), (Bouras et al., 2017). Moreover, price ranges are selected for the SA. There are two types of existing SAs, namely the one-way and the multi-way SA. In the first case, only one individual parameter fluctuates and its effect on the model is studied. In the second case, a set of multiple parameters is combined in order to show how they impact on the model simultaneously and what their relationship with one another and the model is. In most cases, these amounts are relevant with one another and represent cost factors of the same network component, e.g. Base Station, Bandwidth etc.

In this paper, it is considered that 5G is going to be a future technology. Therefore, the prices will be risen or reduced up to 75%. It is considered that several problems and financial issues may lead to recession. The components' pricing could be augmented if financial problems occur or could be reduced if novel highly efficient technologies are introduced in the future network architectures. Values are opted in accordance to today's state and values. Therefore, an adequate price range is opted to cover and include both cases. Based on this concept, several experiments will be conducted to show the tendency of the prices. It is substantial that all 5G key enabling technologies are analyzed in a technoeconomic perspective. In this context, all the different network parameters will be analyzed and thus, the components that are the most influential in the model will emerge as brakes for the networks' evolution. This analysis is rather helpful as it is shown where the investigation should focus, so that these costs will be cut down on.

Table 3: TCO Cost Parameters and System Variables.

RAN Costs			
Parameter	**Description**	**Value**	**Value Range for SA**
CeNB	Capital cost for an eNB	1000€	[250, 1750]
CEPC	Core network's capital cost for the deployment of a single eNB	110 €	[55, 165]
NeNB	Number of eNBs needed	1	[1, 10]
NHeNB	Number of HeNBs needed	50	[10, 100]
I	Annual interest rate	6%	[2, 12]

N	Duration of the installment plan	10	[1, 20]
Fst	Linear coefficient for site costs	0.8	[0.2, 1.2]
Csite	Site costs	3100 €	[775, 5425]
Crun	Running costs	892.5 €	[223, 1561]
fBW	Linear coefficient correlating site annual backhaul costs with provided BW – expressed in €/Gbps	1170	[877, 2047]
BW	MBS Bandwidth for a site's interconnection	10Gbps	[5, 20]
BW	mmWave Bandwidth for a site's interconnection	135Gbps	[30, 300]

6.Experimental Results

The experiments that are conducted show how each network component affects the deployments. The Experimental Process considered is analyzed in Algorithm 1. In this section, based on the developed Mathematical equations, several parameters are introduced and applied for the prices considered. Thus, they help analyzing the most impactful factors that need to be reconsidered, so that all kinds of costs are reduced.

Algorithm 1 Experimental procedure

1: procedure MATHEMATICAL MODELS

2: Calculate Macrocells & Small cells TCO

3: procedure PARAMETERS SELECTION

4: Opt for the parameters for mmWave & MidBand

5: Opt for the price ranges

6: procedure Sensitivity Analysis

7: One-Way SA for the parameters: BW, f_{BW}, C_{eNB}, C_{HeNB}, C_{EPC}, C_{st}, i, n

8: Two-Way SA for the set of parameters: BW-f_{BW}

The experiments below examine all the different types of network components and the costs induced in terms of the different cost categories namely the CAPEX, OPEX and the TCO.

The CAPEX is a very important cost category, as it includes the costs spent during the investment period. The CAPEX is examined versus the number of cells in the deployment. Figure 3 represents the effect of the models in the CAPEX cost. It seems that small cells' CAPEX is affected by the augmentation in the number of cells whereas, the macrocells' CAPEX is not affected so gravely by the increment in the number of added cells.

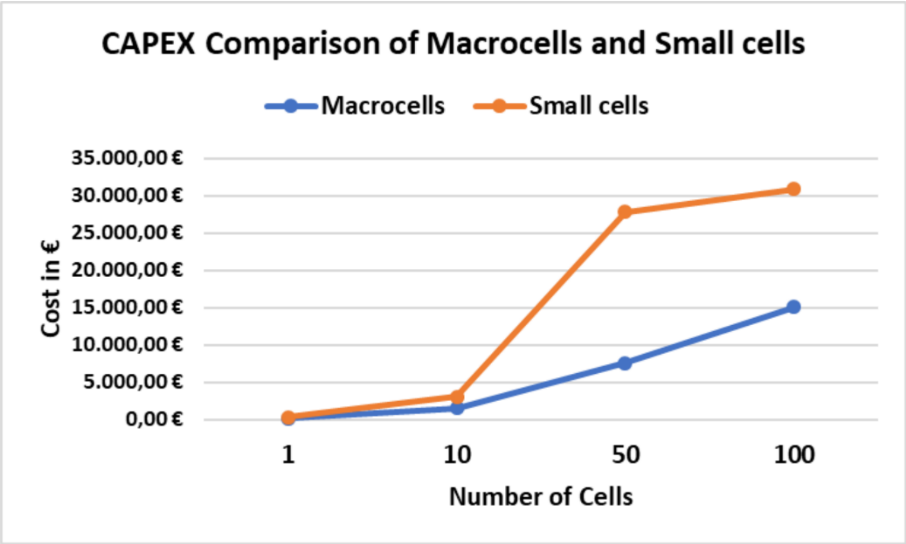


Figure 3: SA of Small Cell and Macrocell CAPEX in relation to the number of cells.

Although, the impact of the number of cells is not the same, this amount is linearly proportional to the CAPEX. Thus, the models depend on the CAPEX. In the case of small cells, these costs are paid by the cell owner, but on the other hand, in the microcellular case by the telecommunication provider.

The OPEX is a very important cost category, as it includes the costs spent for the system's operation, coordination and managing activities. The OPEX is examined versus the number of cells in the deployment. Figure 4 represents the effect of the models in the OPEX cost. It seems that macrocells' OPEX is affected by the augmentation in the number of cells whereas, the small cells are not affected much by the increment in the number of added cells. Although, the impact of the number of cells is not the same, this amount is linearly proportional to the OPEX. Thus, the models depend on the OPEX. In the case of small cells these costs are paid by the cell owner, namely the consumer, but on the other hand, by the telecommunication provider.

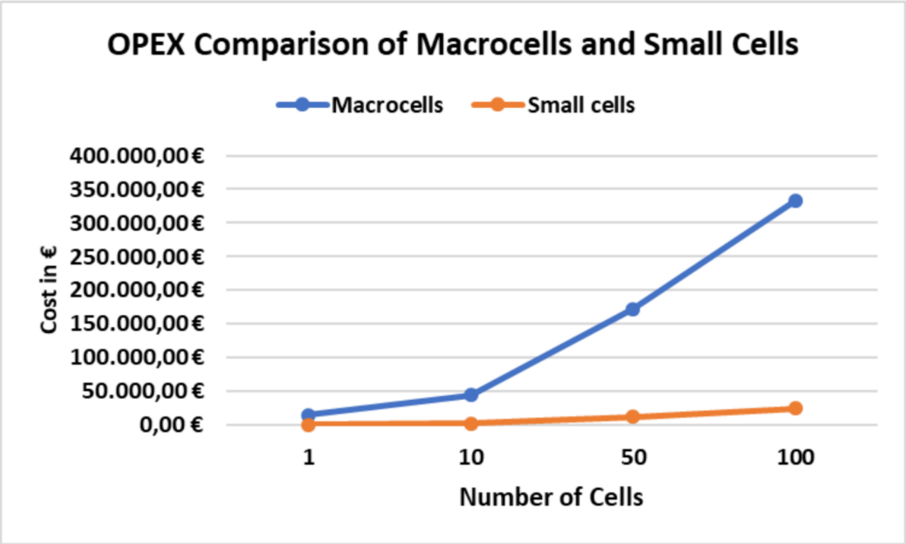


Figure 4: SA of Small Cell and Macrocell OPEX in relation to the number of cells.

The TCO is a very important cost category, as it includes the costs spent for the system's deployment and operation, coordination and managing activities. The TCO is examined versus the number of cells in the deployment. Figure 5 represents the effect of the models in the TCO cost. In both models, this amount is linearly proportional to the TCO. In the case of small cells these costs are paid by the cell owner, namely the consumer, but on the other hand, by the telecommunication provider.

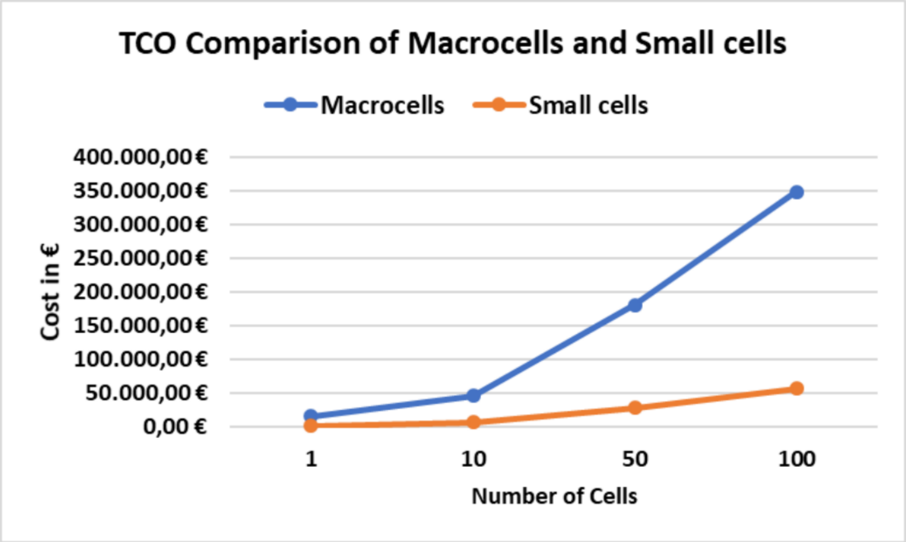


Figure 5: SA of Small Cell and Macrocell TCO in relation to the number of cells.

6.1 One-way SA of the cost parameters

The cost for the node is not very substantial in the formation of any cost category, namely the CAPEX, OPEX and TCO. The augmentation of the pricing of eNodeB does not induce an increase on the other costs. Figure 6 indicates the relationship between the eNodeB with the Macrocell costs.

The Evolved Packet Core (EPC) is a substantial parameter that is related to the networking equipment. The impact it has on all the cost categories of the deployments is analyzed in Figures 7 and 8. For the macrocellular case it does not affect any of these cost parameters. For the small cell case, it affects all the different cost categories and the pricing of the EPC. It affects the CAPEX, OPEX and the TCO.

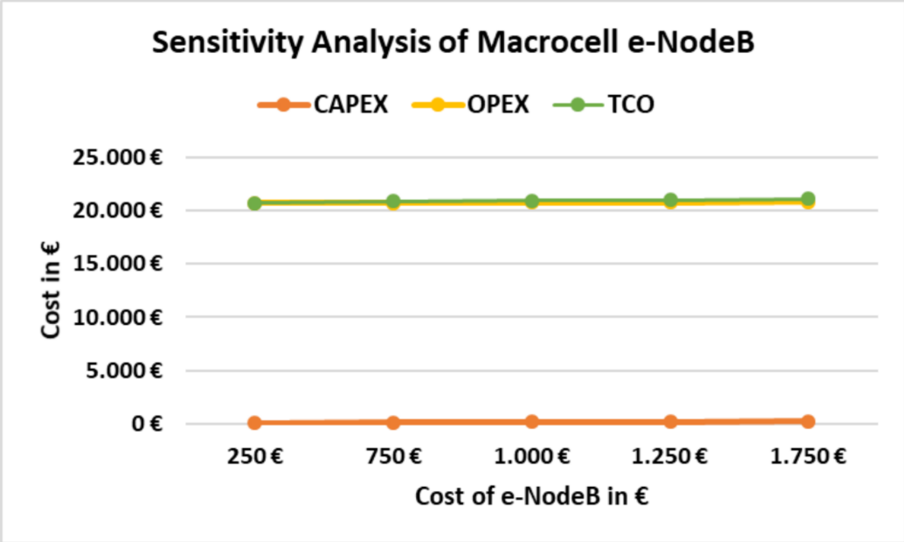
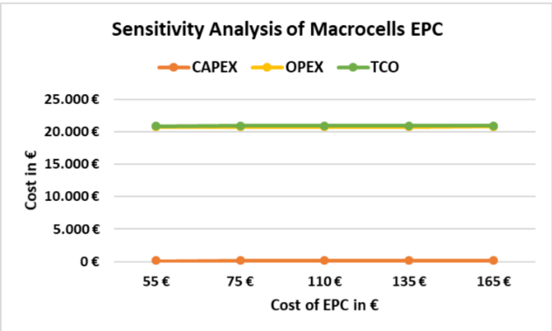


Figure 6: SA of Macrocell CAPEX, OPEX and TCO in relation to the eNB.



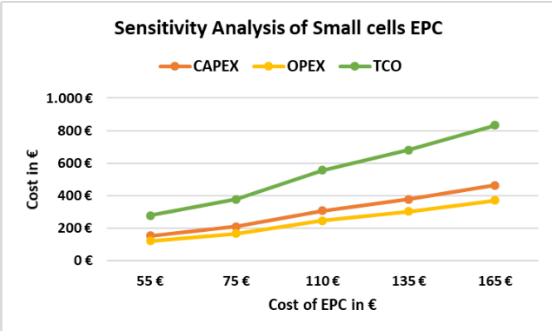
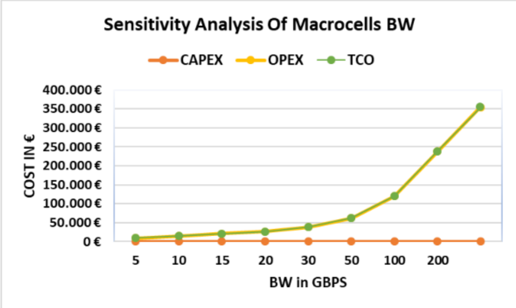


Figure 7: Macrocells vs small cells SA of Macrocell CAPEX, OPEX and TCO in relation to the EPC.

Figure 8: Macrocells vs small cells: SA of Small cell CAPEX, OPEX and TCO in relation to the EPC.

BW is a very essential cost category, as it appears to have an impact on several cost categories and it is an indispensable part for the network's operating.



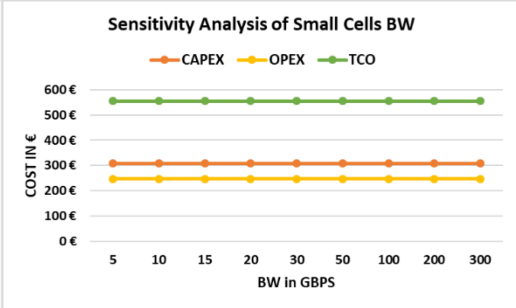
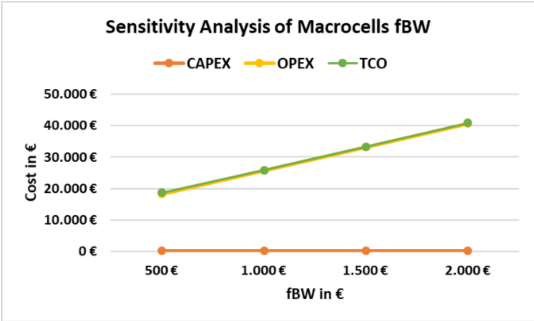


Figure 9: Macrocells vs small cells: SA of Macrocell CAPEX, OPEX and TCO in relation to the BW.

Figure 10: SA of small cells CAPEX, OPEX and TCO in relation to the BW.

Figures 9 and 10 indicate the relationship between BW and the different costs. In the case of macrocells, this cost category affects the OPEX and the TCO, specifically for data rates larger than 50GBps. The CAPEX is not affected by BW. The small cells are not impacted by BW. This is normal as the BW is leased by the telecommunication operators, therefore, is related to the macrocell costs. On the other hand, for the small cells the BW does not affect the consumers as it is paid by the provider.

f_{BW} is a very essential cost category, as it appears to have an impact on several cost categories and it is an indispensable part for the network's operating. Figures 11 and 12 indicate the relationship between BW and the different kinds of costs. In the case of macrocells, this cost category affects the OPEX and the TCO, specifically for BW larger than 50GBps. The CAPEX is not affected by BW. The small cells are not impacted by BW. This is normal as the BW is leased by the telecommunication operators, therefore, are related to the macrocell costs. On the other hand, for the small cells the BW does not affect them as the BW is paid by the provider.



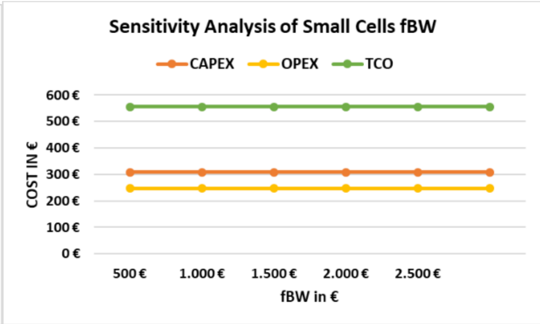
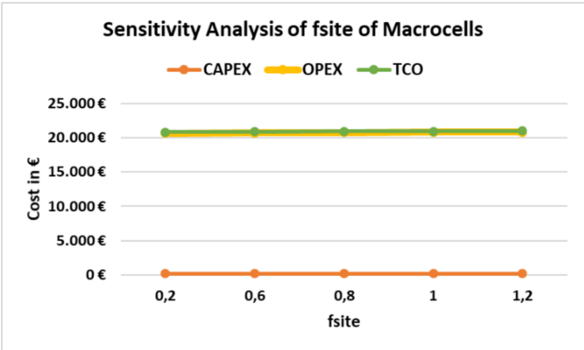


Figure 11: Macrocells vs small cells SA of Macrocell CAPEX, OPEX and TCO in relation to the f_{BW}.

Figure 12: Macrocells vs small cellsSA of Small cell CAPEX, OPEX and TCO in relation to the f_{BW}.



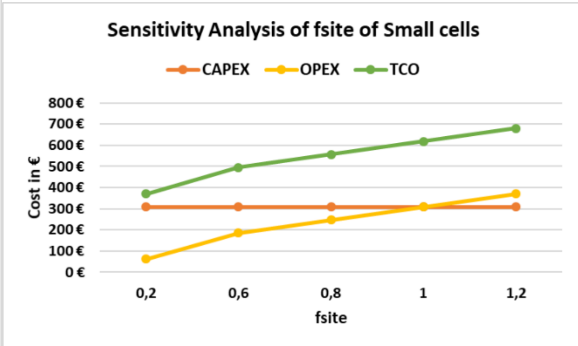
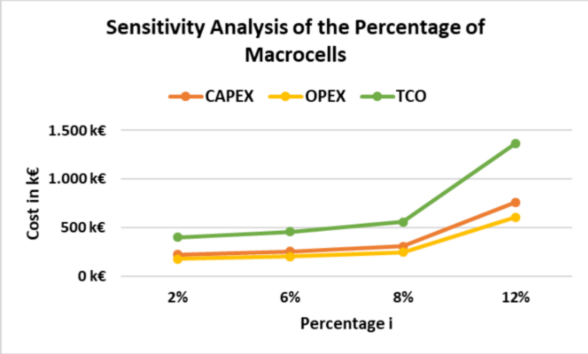


Figure 13: Macrocells vs small cells SA of Macrocell CAPEX, OPEX and TCO in relation to the f_{st}.

Figure 14: Macrocells vs small cells SA of Small Cell CAPEX, OPEX and TCO in relation to the f_{st}.

The siting costs f_{st} are examined thoroughly, as they affect the siting of the cell. This cost category does not play an important role in terms of costs for the Macrocellular deployment. This cost only exists in Macrocells' OPEX and does not appear in CAPEX or small cells' costs. Figures 13 and 14 represent the relationship of siting costs in relation to the Macrocell CAPEX, OPEX and TCO. For the small cell case, it mainly impacts the OPEX and TCO. The augmentation of the f_{st} is linearly proportional to the OPEX and TCO.



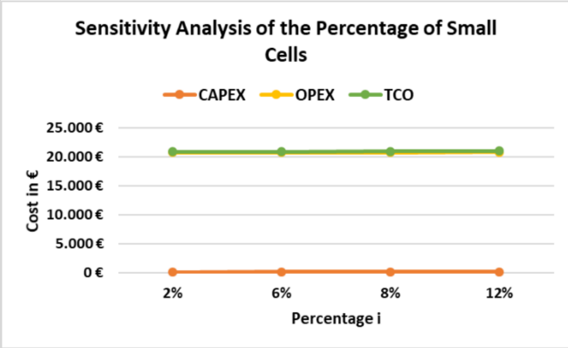
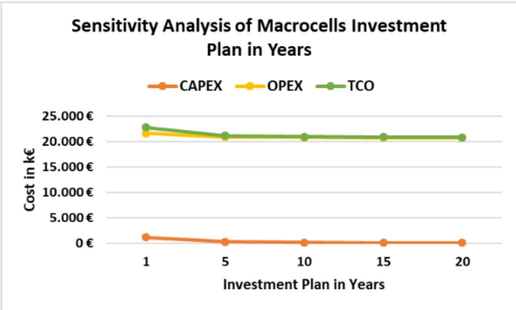


Figure 15: Macrocells vs small cells SA of MacroCell CAPEX,OPEX and TCO in relation to the *i*.

Figure 16: Macrocells vs small cells SA of Small Cell CAPEX, OPEX and TCO in relation to the *i*.



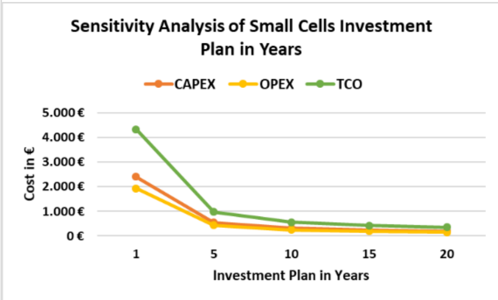


Figure 17: Macrocells vs small cells SA of MacroCell CAPEX, OPEX and TCO in relation to the years of investment *n*.

Figure 18: Macrocells vs small cells SA of Small Cell CAPEX, OPEX and TCO in relation to the years of investment *n*.

i is a very essential parameter, as it appears to have an impact on several cost categories and it is an indispensable part for the network's investing period. It consists the loan that need to be paid. Figure 15 and 16 indicate the relationship between the interest rate and the different kinds of costs. In the case of macrocells, this cost category affects all types of costs. The small cells are not impacted by *i*.

n is a very essential parameter, as it appears to have an impact on several cost categories and it is an indispensable part for the network's investing period. It consists the years of investment. Figure 17 and 18 indicates the relationship between the years of investment and the different kinds of costs. In both cases, this amount affects all types of costs especially when the years of Investment are less than 5. This amount is inversely proportional to the number of years of investment.

The siting costs C_{site} are examined thoroughly, as they affect the siting of the cell and thus, have an impact on the OPEX and the TCO. This cost only exists in Macrocells OPEX and does not appear in CAPEX or small cells' costs. Figure 19 represents the relationship of siting costs in relation to the Macrocell CAPEX, OPEX and TCO.

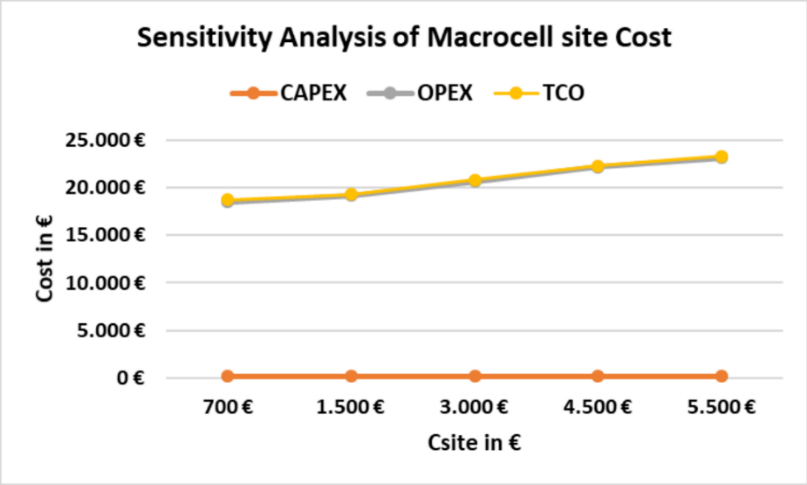


Figure 19: SA of Macrocell CAPEX, OPEX and TCO in relation to the C_{site}.

In general, small cells' CAPEX is mainly affected by the EPC costs, the interest rate and the period of investment. Small cells' OPEX is mainly affected by the siting costs and the interest rate. The larger the period of investment the more the investment reciprocates. Therefore, it becomes an absolute necessity that these costs are limited. Technological advancements are necessary so that small cells become of higher performance, of lower cost and more ecological. Subscribers should calculate the costs induced by small cells and evaluate the advantages in order to be able to know whether they really need to invest in or not. What is more, the macrocells are impacted by BW costs and the period of investment. Novel technologies related to BW should be adopted in order to reuse frequency bands, virtualize them etc.

6.2 Two-way SA of BW

The two-way SA is chosen for the BW related costs. In the presented model, BW is represented by two different parameters. Therefore, it is considered that the combination of these two parameters is substantial for the model's viability and plays an important role in the cost formation. These parameters also affect one another. BW is one of the most fundamental network factors as it is necessary for the network's operation and also because its pricing does not only depend on technological and network issues, but it also depends on the bidding authority that sells the needed spectrum to the network providers. As it is shown above, the Macrocells mainly impact the OPEX and therefore the TCO. So they do not impact the CAPEX. Thus, the CAPEX is not analyzed in this case.

As a result, the parameters *BW* and f_{BW} that mainly affect the model are analyzed in order to review the way they impact the OPEX and the TCO. When the parameters augment, the OPEX augments as well. Since the BW has an effect on the OPEX, the TCO also increases. In accordance to Figures 20 and 21, it is indicated that by augmenting the BW parameters, the OPEX and the TCO augment as well. When the range of the spectrum increases, then the costs also raise. As a result, the proper equilibrium among the spectrum and the pricing should be succeeded for the wide adoption of this frequency value range.

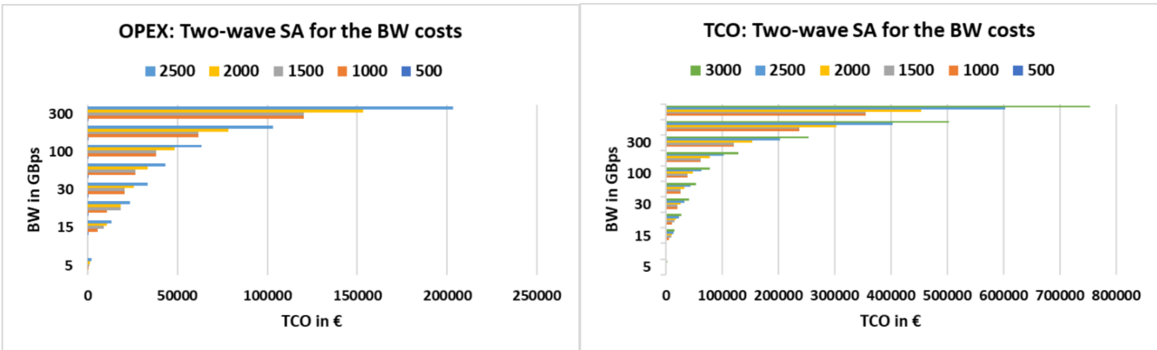


Figure 20: Two-way SA of Macrocell in relation to the f_{BW} and *BW*- OPEX.

Figure 21: Two-way SA of Macrocell in relation to the f_{BW} and *BW*- TCO.

7. Conclusions

In this section, the conclusions gathered by the experimental process are summarized. In this paper, Macrocells and Small cell models were presented. A thorough analysis of several frequency bands was considered, namely, frequencies of the mmWave and Midband were investigated for the two different models. In these terms, following a Sensitivity Analysis for all the network parameters, several conclusions are summarized.

Firstly, the two different deployments are affected by different network components or financial parameters. As a result, Macrocells are mainly affected by the Bandwidth costs, the interest rate, the years of investment and site costs. Macrocell need much Bandwidth in order to operate properly. Operators that obtain these cells need to lease frequencies and cover their clients demands. As a result, these costs augment the OPEX. Interest rate alongside with the years of investment are financial parameters. These parameters affect mainly the CAPEX cost as they consist of assumptions that need to be made for money in loans during the investment period. Thus, the more the years of Investment the better it is for the providers. Site parameters are obtained by the system's operation and therefore bear the OPEX costs in this technology.

For the small cell case, there is a whole different approach. Small cells, namely picocells, femtocells etc. are obtained by the user in their premises. For example, an office or a homeowner decides to install this equipment in order to enhance the signal and enjoy better network coverage. As a result, there are not any siting costs, as the equipment is placed in the building of the owner, there is no need in BW leasing as the BW is obtained via the contract made with the telecommunication company. The only significant costs included are the existing equipment namely the EPC equipment, which falls into the CAPEX cost category and the power consumption costs that fall in the OPEX category. Maintenance and operation activities do not have an impact on the model as the users become able to maintain the equipment on their own or on a very little cost.

8. Future Work

Future Research in the field of mmWave is suggested in this section. Although, mmWave seems to be an efficient alternative for the 5th generation of mobile networks, there are still a lot of debatable issues and open questions concerning its prevalence. On the one hand, using mmWave unused frequencies and bands could enhance the networks, but on the other hand, a lot of problems appear and should be resolved so that this mobile network technology is highly adopted.

The mmWave frequencies are expensive, especially in terms of Operational expenditures, as frequencies are leased and therefore, money are paid for the auctioning process and the leasing by the operators. In accordance to the already presented model, mmWave technologies bring about large maintenance costs, thus it is of great significance that power expenses and Bandwidth are renegotiated, so that lower prices are succeeded.

What is more, there is a need for more Virtualized equipment and also there is a need for reducing the equipment. This could happen using more optimized algorithms and lower amount of network components. This fact will lead to higher performance, smaller deployments that induce lower Operational Expenses.

Finally, novel techniques should be developed, or existing reallocating algorithms should be updated so that Bandwidth resources are reused and less frequencies are needed in the future so that the users' mobile needs and connectivity are highly and efficiently covered.

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