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Techno-economic comparison of MIMO and DAS cost models in 5G networks

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Abstract

High communicational standards have been set for the 5G mobile networks. Therefore, it is of great importance that technological solutions that include all the significant features, such as the high coverage and capacity and low round-trip delays, are adopted for the next generation of mobile networks. Except for their technical efficiency, these technologies should be profitable for providers as well. As a result, the need for limiting the costs spent for the development of these technologies emerges. In this papers, four models two for each one of the two solutions for 5G networks are developed, namely the Multiple Input Multiple Output (MIMO) and the Distributed Antenna System. The architectural models assumed for the techno-economic analyses are presented. The mathematical models for both technologies are developed. Experiments are conducted using prices of the Greek market and also Sensitivity Analysis (SA) is used to pinpoint, which cost parameters are the most expensive ones and therefore it is likely that they discourage providers to invest in them. To our knowledge there are not many studies comparing and contrasting these technologies and there is no SA for MIMO. Therefore, it is considered that research for these models is of vital importance for the next generation of mobile communication networks, as they are foundation stonesfor the formation of 5G.

Keywords 5G · DAS · Modified DAS · MIMO · Massive MIMO · Sensitivity analysis techno-economic comparison

1 Introduction

Advantages of 5G networks are of great importance for humanity, but its huge requirements will require a few different technologies and apporaches to be followed so that they are met. Scientific, research and operator communities have set the fundamentals for this generation, such as incessant coverage, higher capacity and lower delays. What is more, novelty and modern services will be provided by this generation, such as the Internet of Things (IoT), Device-to-Device (D2D) and Machine to Machine (M2M) communications etc. All these achievements will gradually create a huge load of data for mobile networks, as the number of devices in networking infrastructure exponentially augments day by day.

On the other hand, the global economic crisis that is plaguing the business sector, pushes operators to seek extra income, while limiting all the expenses. The requirements of 5G can not be met by the technologies, that have been used until recently and thus, novelties or modifications of the already existing infrastructure should be used in order to cover the network efficiently.

In this context, it is of great importance that not only more efficient technologies are adopted, but also the old infrastructure evolves so that it becomes compatible with the next generation. All cornerstone technologies should be analyzed in a techno-economic way. Different approaches should be followed for the existing technologies. Developing technical scenarios, mathematical models alongside

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with experimentation in the field becomes inevitable. Techno-economic analysis is a strong technique that helps analyzing pricing models and depicting costs in terms of some parameters. Sensitivity Analysis (SA) is the technique, which helps indicating the factors that influence the overall model, while one or more parameters fluctuate within a given value range. For example, in the case of pricing models, SA shows how each parameter affects the different types of expenditures, namely the Capital (CAPEX), the Operational (OPEX) and the Total Cost of Ownership (TCO).

Network Function Virtualization (NFV) is a technology that is used so that hardware is replaced by software. This technology reduces the hardware infrastructure, costs, power consumption, management and maintenance activities. Distributed Antenna Systems (DAS) is a technology that appeared the 1980's, but wasn't spread immediately. The last few years, there is a lot of research in the field of DAS. In the United States of America (USA) much research has focused on DAS, because it constitutes a possible solution for 5G networks. Multiple Input Multiple Output (MIMO) is a technology that has already appeared in the networks. It is rather helpful for better transmitting the signal as there are more than one transceivers and receivers within its basic form. Massive MIMO is a variation of the MIMO, that contains an augmented number of transmitters and receivers.

In this paper, these two technologies (namely the DAS and the MIMO technologies)consist probable solutions for 5G, are compared and contrasted. What is more, several scenarios are developed for the experimental procedure. The DAS is modified by using Network Function Virtualization (NFV) and a different approach emerges. A model of Massive MIMO is also presented. Moreover, mathematical models for both technologies are included. The parameters of the models are opted in accordance to the Greek Market. SA is conducted to show how costs affect the overall pricing models.

Authors have already presented pricing models of other 5G solutions. They have analyzed the Software Defined Networking (SDN) technology in a techno-economic way [1]. They have developed techno-economic models for Ultra-dense deployments and DAS [2] and also SA of the previously mentioned technologies [3, 4]. To our knowledge there is not much research activity in the field of techno-economic analysis of 5G technologies. There is not a research activity comparing and contrasting DAS and MIMO. There is not any study modifying the DAS model using the NFV concept.

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

2 Related work

In this section an overview of the related research in the field is summarized. In particular, studies developed in the field are presented. 5G, DAS, MIMO and techno-economic analyses are summarized.

Alongside with 5G, IoT and D2D will dominate. Many studies claim that in western societies there will be more than 5 simultaneously connected devices per person. As a result, even inside households capacity will become a very challenging issue. Establishing a very efficient network infrastructure in existing and new buildings is becoming a growing need. DAS is a promising solution and could lead to enhance network accessibility and cover the devices connected into IoT and D2D communications.

5G 5G networks are analyzed in [5]. Pricing models for Ultra-dense deployments are presented in [6, 7]. Elmannai and Elleithy [8] promises that following the authors' proposals, the cost per bit could remain the same. Analysis on opportunities on Service Level Agreements (SLA), which consist promising financial opportunities for providers and telecommunication operators, have been analyzed in [9, 10]. Cloud computing is a technology of 5G networks and techno-economic models have been already presented for it [11]. The technologies that are going to be used for the 5th generation and will lead to meeting the fundamental requirements of 5G, such as SDN, MIMO, NFV, cloud etc. have already been presented [12]. In [1] authors presented cost models of SDN & NFV based on 5G solutions and in [13] they have presented a comparative analysis concerning the SDN & NFV solutions in mobile 5G networks.

DAS [2] describes a basic techno-economic comparison of Ultra-dense and DAS deployments. Authors expanded this analysis conducting SA [3, 4]. Dynamic DAS [14] is supposed to succeed in providing better coverage and capacity and lower noise levels. DAS is also analyzed in a techno-economic way in [15]. In this work, the most significant pricing considerations of the model are analyzed. The network architecture regarding the structure of the DAS proposed architecture for the case of Western Europe and China are presented. Authors, have already presented cost models comparing DAS and femtocells in [2] concluding that if DAS Capital (CAPEX) and Operational (OPEX) expenditures were reduced, DAS could consist an important alternative for 5G. In [3, 4] authors presented a

SA including the parameters that play the most fundamental role into the cost formation. It was concluded that DAS' Total Cost Of Ownership (TCO) is strongly affected by bandwidth and site costs. Although, DAS has been analyzed in a techno-economic perspective in studies, such as: [2–4, 14, 15], There is not any study combining NFV concepts with DAS to diminish its greater costs.

MIMO An optimal design for base stations is discussed in [16], where it is pinpointed that MIMO unresolved issues focus mainly on finding the equilibrium among the appropriate bandwidth (BW) needed, the quantization number in bits and the number of antennas needed to maximize the sum of achievable rates. MIMO technology has been thoroughly researched in [17], while in terms of performance MIMO has been thoroughly investigated in [18, 19]. When it comes to cost analysis, the main existing study [20] compares and contrasts the MIMO with the Licensed Shared Access (LSA) in Finland. Although, MIMO has been thoroughly analyzed in a technical way, there is not much research concerning pricing models of the technology.

3 Alternative deployments

In this section, the scenarios and models for the alternative deployments are presented. The analysis of the architectural models contributes in developing the basics upon which the mathematical and experimental analyses are set.

3.1 MIMO

MIMO is a technology that is considered to be a key enabler for the 5th generation of mobile networks. Several antennas exist on the transceiver's and the receiver's sides contributing in the better exchange of information between the source and the destination and the overall optimization of the communications in the network. MIMO has appeared since the 3rd generation of mobile networks. Nowadays, evolved technological approaches, such as the smart antenna technology, are used to differentiate it, address and meet the new demands raised by these generations of mobile networking.

MIMO MIMO exists in the side of the Base Stations (BS). Several antennas are possible to exist on both sides (transceiver's, receiver's) covering adequately both the source and the destination. It is possible that alternate amounts of antennas exist on each side. Usual number of antennas for MIMO scenarios are 4, 8, 16.

Massive MIMO 5G is setting demanding goals and pushing into novelty. In this terms, MIMO has been alternated to cover the excessive demands of the 5th generation in another form with highly augmented number of antennas, which is called Massive MIMO. For instance, if more than 64 antennas exist on a side of the MIMO, then this kind of MIMO is called Massive MIMO. Usual number of antennas for Massive MIMO are: 64, 128, 256.

MIMO has to face very important drawbacks, namely the need for the optimization of the Bandwidth (BW), the quantization numbers in bits and the costs occurred by the antennas added. On the other hand, the most fundamental advantages of MIMO are:

- augmentation of coverage
- reduction of latency
- enhancement of data rates

In this paper, there are two different scenarios followed for MIMO. On the one hand, it is considered that there exist 2, 4, 8, 16 antennas on each side (source, destination). This analysis is considered to be the analysis for the MIMO case. And also there is an analysis for 64, 128, 256, 512 antennas on each side, which is the Massive MIMO case. Figure 1 indicates how a MIMO model is formed. (A transceiver and a receiver and a number of *N* antennas are included and a lot of signals are exchanged on both sides.) For both cases, the MIMO technology considered in the mmWave one.

3.2 DAS

DAS is a technology that uses a number of antennas in order to enhance the coverage of a building or an area that is equivalent to a macrocellular one, therefore there are two types of DAS, namely the indoor and the outdoor, covering the respecting areas. The DAS includes a number of antennas in its basic structure, that are connected via medium e.g. fiber optic, coaxial cable etc. When combined with other wireless technologies, e.g. 802.11 can help enhancing the network's efficiency.

On its basic structure there are two antennas, one for the transmission and one for the reception. Equipment helps

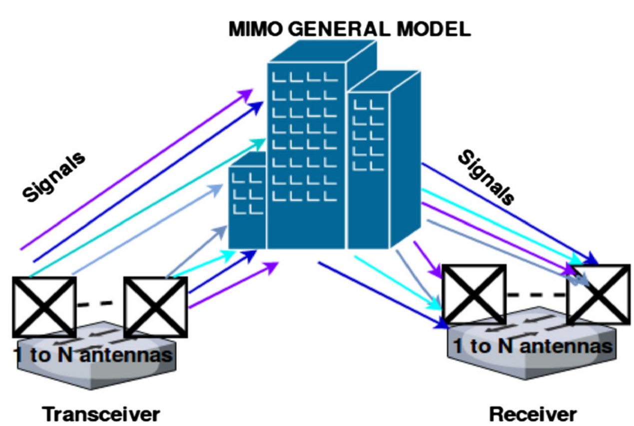

Fig. 1 The MIMO basic model

the Radio Frequency signals to be properly transmitted. Several feeders and transceivers are occasionally added in the structure. All the previous parts consist the Distributed System (DS). There are also BSs added to this infrastructure. For a small building 2 antennas per floor are adequate to cover the building. For larger and overpopulated places, several antennas are added.

On the other hand, using the NFV concept could contribute in the replacement of some equipment e.g. BS and antennas with virtualized ones. Moreover, there are techniques that could contribute to virtualize the needed BW which helps improving the BW reallocation and exploiting all the available frequency bands.

Figure 2 indicates the two developed models for the infrastructure of the DAS solutions. In the DAS architecture, there are *N* floors in a building, several antennas on every floor, which are interconnected. Antennas communicate with one another and with the antenna at the roof of the building which performs the communication with the BS antenna. There are several devices (receivers, transceivers) that are used to enhance the transmitted signals. The overall architecture is similar to the one for the simple DAS, but the antennas (indoors and outdoors) as well as the BS and the BW are virtualized components.

DAS appears to have several advantages, such as better coverage, scalability and augmented network capacity. On the other hand, it appears to include several drawbacks, the most substantial of which is the high operational costs due to the big number of antennas.

3.3 Comparison

Table 1 summarizes the basic comparison of the most fundamental features of the different solutions of this

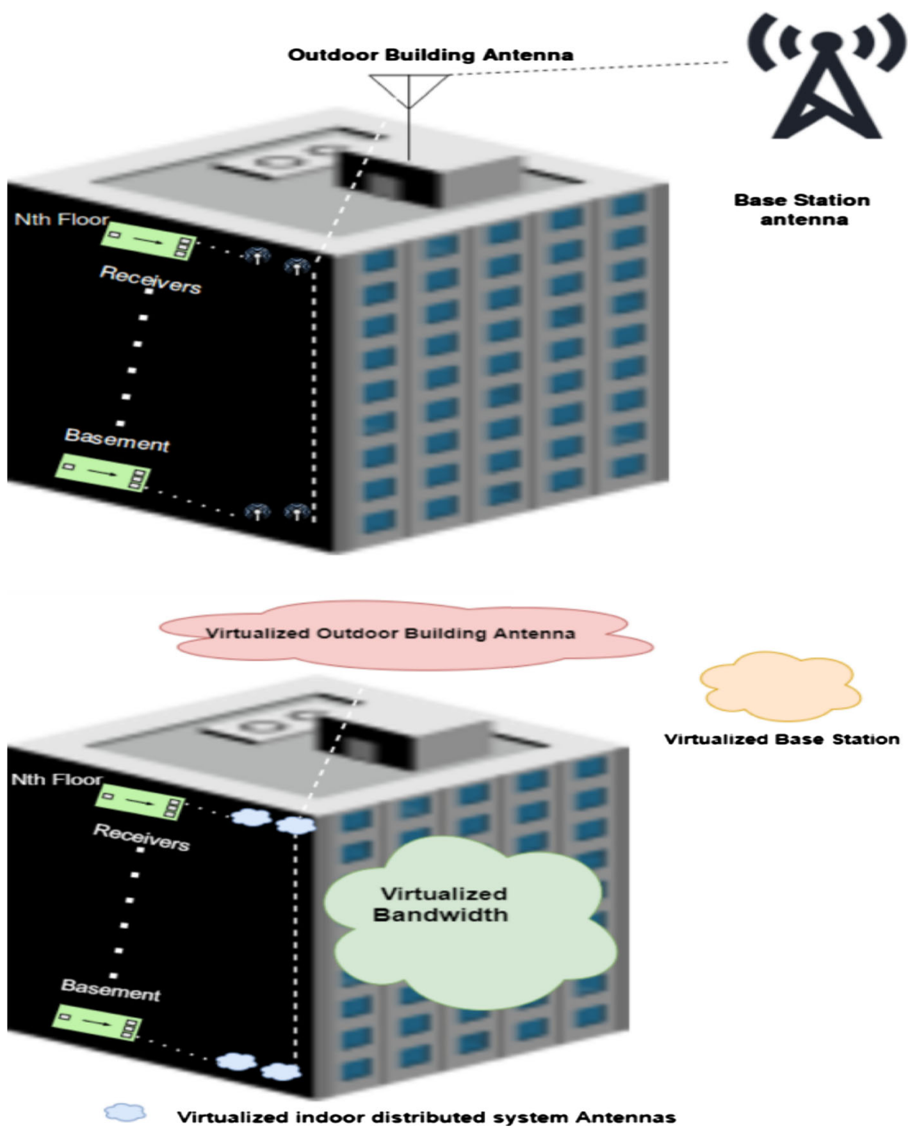

Fig. 2 The DAS models

Table 1 Comparison of the basic characteristics of the MIMO and DAS models of the paper

Factor	Solution			
	DAS	Modified DAS	MIMO	Massive MIMO
Cost	High OPEX	Reduced OPEX	High OPEX	High CAPEX/OPEX
Scalability	✓	✓	✓	✓
High performance	✓	✓	✓	✓
High coverage	✓	✓		✓
Possibility for heterogeneous deployments	✓	✓	✓	✓
BW	Ghz frequency bands	Ghz frequency bands	Ghz frequency bands	Ghz frequency bands
High interference				✓
Appearance	1980's	Proposal	1970's	2010's
Adoption	1990's	–	2000's	2020's(?)

paper. All technologies include high OPEX, but in the proposed model those costs are reduced thanks to the NFVs. What is more, all technologies are scalable as one or more antennas could be added/extracted from the architecture. They are models of high performance and coverage. They can easily be combined with other technologies as they are compatible with most wireless and/or mobile solutions, so heterogeneous structures could result. They all include high frequency bands that vary a little from one technology to another. The highest interference is pinpointed for the case of Massive MIMO, as they include larger number of antennas and they are in a really close distance. Although, DAS implementations also include large number of antennas they are spread in the covered location, therefore interference does not reach such high rates.

A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is a technique that helps indicating how several facts 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 that derive from internal and external factors respectively. Weaknesses and Threats are both harmful that derive from internal and external factors respectively.

In the following section, a SWOT analysis lists the Strengths, Weaknesses, Opportunities and Threats that are pinpointed by adopting this technologies. Although both technologies appear to have several strong points especially in terms of performance and efficiency, they face several weaknesses, such as the interference issue. What is more, providers (external factor) may have distrust to invest in new solutions, but on the other hand 5G's advent is imminent and companies will not want to have obsolete equipment.

	Helpful	Harmful
Internal origin	1. MIMO & DAS include important benefits and are ideal solutions for wireless and mobile networks 2. Both are scalable technologies (Several antennas could be added or extracted) 3. They are compatible with one another and also with other solutions as well 4. They are combinatorial with one another and also with other solutions as well 5. They offer mechanisms that enhance the availability of network resources	1. They are both dependent on high OPEX costs (BW, equipment, Backhauling etc.) 2. Require equipment and/or modifications so that they are adapted to 5G 3. Interference issues related to the included antennas have not been completely faced 4. Fully green energy in the network architectures has yet to be achieved 5. Large infrastructures induce high cost implementations
External origin	1. 5G's advent 2. Conventional Technologies do not meet 5G demands therefore, research in the field it becomes a necessity and also an opportunity 3. Novel services and products are linked to 5G 4. 5G networks will be very different than today's network therefore more complex, combinatorial and heterogeneous solutions will be needed	1. Investing in new products/equipment etc. is needed by the providers 2. Distrust by providers about the trade-off between investment vs profit 3. Distrust by providers about the trade-off efficiency/advantages vs expenses 4. Former investments (of LTE-A) technologies may have not full reciprocate yet

4 Cost analysis

The total cost of owning a solution could be split in two main categories:

- *CAPEX* costs paid during investing in a new technologies. It includes the costs for the equipment bought, the installation and implementation costs and all costs related to hardware that need to be added so that the system is built from scratch.
- *OPEX* expenditures include the costs of day-to-day coordination and operation of the system. Several expenses, such as bandwidth leasing costs, power

consumption costs, maintenance activities etc. should be included in this cost category.

The two types of costs are extremely different and therefore, it is difficult to calculate the actual cost of each category. What is more, there are several other important issues that need to be considered. For instance, how much will every network component cost in 2–5 years?

The CAPEX/OPEX expenditures are paid on a yearly basis and they consist a form of loan. A principal amount of the expenditure is repaid anually, thus the economic repeating payment factor could help provision expenditures for future years. This will be useful for the CAPEX, OPEX and TCO as it consists a way of foreseeing the amounts that have to be paid on an annual basis.

The repeating payment equation [2] is introduced so that the assumption of obtaining loan is considered. Given a principal amount P, this amount should be given every year. Therefore, the expenditure will be given by:

$$A = P\frac{r(1+r)^n}{(1+r)^n - 1} \quad (1)$$

where r represents the periodic interest rate and n represents the number of payments, i.e., the length of the installment plan in years.

4.1 MIMO

The TCO of MIMO could be split in two different categories, the CAPEX and OPEX.

4.1.1 Capital expenditure

C_{eNB} represents the cost of a BS and C_{EPC} is the cost for the Evolved Packet Core (EPC), then the cost for a Single BS will be given by the expression: : $C_{eNB} + C_{EPC}$. Given that the network includes B BS, then the total cost for all BSs will be: $B(C_{eNB} + C_{EPC})$. What is more, for the MIMO technology antennas are added in the side of the source and the destination. Therefore, this number should be considered as well. Assuming that different number of antennas are added on each side, then M_s and M_d represents the number of antennas for the source and the destination respectively, and the total cost of the BS with the MIMO equipment, namely the CAPEX cost will be, [using the Eq. (1)]:

$$C^{CX}_{MIMO} = B(C_{eNB} + C_{EPC})(M_s + M_d)\frac{r(1+r)^n}{(1+r)^n - 1} \quad (2)$$

where C^{CX}_{MIMO} is the annual total CAPEX, and n is the installment plan in years.

4.1.2 Operational expenditure

The costs for running the system: day to day management, power consumption etc. are included in c_{run}. Back-hauling costs are included in c_{bh}. Thus, if B BS exists the cost is formated as: $B(c_{run} + c_{bh})$. Given that there are M_s and M_d antennas for the source and the destination respectively then: $B(c_{run} + c_{bh})(M_s + M_d)$.

c_{st} includes the costs for site, operation and support. There are B BSs so Bc_{st} represents this amount. The BW that is available for usage is represented by BW and should be multiplied with a coefficient f_{BW} that represents the cost for the BW leasing and other supporting activities.

Therefore, the total OPEX for the MIMO is:

$$C^{OX}_{MIMO} = (M_s + M_d)\left[B(c_{run} + c_{bh})(C_{eNB} + C_{EPC})\frac{r(1+r)^n}{(1+r)^n - 1} + Bc_{st} + f_{BW}BW)\right] \quad (3)$$

4.1.3 Total cost of ownership

The TCO is given by adding CAPEX and OPEX, thus:

$$c^{TCO}_{MIMO} = B(C_{eNB} + C_{EPC})(M_s + M_d)\frac{r(1+r)^n}{(1+r)^n - 1} + (M_s + M_d)[B(c_{run} + c_{bh})(C_{eNB} + C_{EPC})\frac{r(1+r)^n}{(1+r)^n - 1} + Bc_{st} + f_{BW}BW] \quad (4)$$

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

4.2 DAS

DAS TCO is split into CAPEX and OPEX as well.

4.2.1 Capital expenditure

BS costs are a part of the CAPEX. The DAS BS costs are represented by the equation: $C_{eNB} + C_{EPC}$. C_{eNB} and C_{EPC} are the costs for eNB and EPC respectively. Given that there are N BSs, then: $N(C_{eNB} + C_{EPC})$. The cost formation results from the Eq. (1), since the money spent on the BS are a repeating payment. BS costs will be:

$$C^{CX}_{BS} = N(C_{eNB} + C_{EPC})\frac{r(1+r)^n}{(1+r)^n - 1} \quad (5)$$

where i represents the interest rate and n the installment years considered.

For the DAS distributed system d antennas should be added and a cost C_{eq}, should be paid to obtain the equipment. Therefore:

$$C_{DASEQ}^{CX} = C_{eq} d \frac{r(1+r)^n}{(1+r)^n - 1} \tag{6}$$

where C_{DASEQ}^{CX}, is the annual total cost of DS equipment CAPEX.

Implementing the system induces a cost, represented by the parameter C_{inc}, which includes the costs for the system's coordination.

The total CAPEX is the sum of all the previous amounts, therefore it is:

$$C_{DAS}^{CX} = (C_{eq} d + N(C_{eNB} + C_{EPC})) \frac{r(1+r)^n}{(1+r)^n - 1} + C_{inc} \tag{7}$$

where C_{DAS}^{CX} is the total DAS CAPEX on an annual basis.

4.2.2 OPEX

The costs for running the system: day to day management, power consumption etc. are included in c_{run}. Back-hauling costs are included in c_{bh}. Thus, if N BSs exist the cost is formated as:

$$C_{BSDAS}^{OX} = N(c_{run} + c_{bh})$$

Maintaining the system induces OPEX. The C_{eq} is the cost for a DS and d is the number antennas and distributed systems in the whole building. This OPEX is therefore:

$$C_{DSDAS}^{OX} = C_{eq} d \frac{r(1+r)^n}{(1+r)^n - 1}$$

Power consumption cost for the DS is represented by C_{pw}. The BW that is available for usage BW should be multiplied with a coefficient f_{BW} that represents the cost for the BW leasing and other supporting activities. Therefore, annual OPEX is considered as:

$$C_{DAS}^{OX} = N(c_{run} + c_{bh}) + f_{BW} BW + (f_{st} + C_{pw} C_{eq} d) \frac{r(1+r)^n}{(1+r)^n - 1} \tag{8}$$

4.2.3 TCO

The TCO is the sum of the Eqs. (7) and (8) and is given by the following:

$$TCO_{DAS} = (N(C_{eNB} + C_{EPC}) + C_{eq} d(1 + C_{pw}) + f_{st}) \frac{r(1+r)^n}{(1+r)^n - 1} + C_{inc} + N(c_{run} + c_{bh}) + f_{BW} BW \tag{9}$$

5 Pricing parameters

In this section, the prices for the parameters of the model are opted. In particular, parameters vary within a specific data range. The basic price for all these cost amounts is opted in [3]. The SA is based on the fact that prices in the future could either be diminished or augment. It is supposed that a $+/-$ 50% of the values that need to be paid for the cost factors nowadays, may represent the prices of the future. Maybe technological advancements could lead to the reduction of the prices for all network components up to 50%, but on the other hand, financial instability could contribute in the increase of the prices up to + 50%.

Virtualization technique is used for the modification of the DAS model. It is considered that virtualization techniques reduce the prices from 20 to 80%. Therefore, for this model, the prices opted are extracted by the original ones modified to fit this value data range. What is more, by diminishing the costs of certain parameters, e.g. BS costs, other types of costs are lowered as well, such as the power consumption cost, or operational and running costs. This fact happens because less hardware means less power consumption and maintenance activities.

Table 2 includes all the cost parameters, that are opted for the MIMO, Massive MIMO, DAS and the modified DAS scenarios. The parameters, their description, their today's value and their data range are summarized. It is therefore considered that the parameters' selection contributes in the experimental analysis and indicates, which of the cost parameters are the most crucial ones for the cost formation.

6 Experimental results

In this section, the experiments are analyzed. The Eq. (1) shows the process followed for the development of the mathematical models, the selection of the parameters and the SA for the different models. Alternative network factors affect the overall model in a different way. Therefore, it is of vital importance to execute SA for the most important parameters of the model in order to indicate, which parameters are the most cost effective and which need to be limited in the future. What is more, other parameters function individually and therefore, they affect the overall costs in an individual way and other parameters affect the TCO, while they are combined. In this terms, one way SA is used to show which parameter has an effect on the TCO of the model. On the other hand, Multi-way SA could be a possibility for parameters that influence the model in a combinatorial manner.

Table 2 TCO cost parameters and system variables

Parameter	Description	Value [2]	Value range for SA
General costs			
C_{eNB}	Capital cost for a single BS	1000 € [2]	[500, 1500]
C_{EPC}	Core network's capital cost for the deployment of a single eNB	110 € [2]	[55, 165]
B / N	The total number of BS's and EPC's needed	1 [2]	[1,100]
n	Duration of installment plan of a site in years	10 years	[5, 20] [2]
r	Periodic interest rate	6% [2]	[2, 10]
c_{st}	Site costs apart from maintenance cost, e.g., power, in-site and off-site support	3100 € [2]	[1150, 4650]
C_{run}	Running costs, such as single site, in-site, off-site	892.50 € [2]	[446.25, 1338.75]
C_{bh}	Backhaul costs for optic fiber	4800 € [2]	[2400, 7200]
BW	Backhaul BW for a site's interconnection	10 Gbps [2]	[5, 15]
f_{BW}	Linear coefficient correlating site annual backhaul costs with provided BW—expressed in €/Gbps	1170 [2]	[585, 1755]
Parameter	Description	Value [2]	Value range
MIMO costs			
M_s	Factor related to the MIMO antennas at the source	64	[2, 4, 8, 16, 64, 128, 256, 512]
M_d	Factor related to the MIMO antennas at the destination	4	[2, 4, 8, 16, 64, 128, 256, 512]
DAS costs			
C_{eq}	DAS equipment	11900 €	[5950, 17850]
d	Number of DS	2 antennas/floor	[2, 4, 8, 16, 64, 128, 256, 512]
f_{st}	Site maintenance costs	0.8	0.8
C_{pw}	Energy consumption costs	157.68 €	[78.84, 236.54] €
C_{inc}	Implementation costs	2800 €	[1400, 4200] €
C_{eNB}	Capital cost for e Node B	[500,1500] €	1000 €
C_{EPC}	Capital cost for a single eNB	[55, 165] €	110 €
N	Number of the DAS BS	1	1
r	Periodic interest rate	[2, 20]%	6%
Modified DAS costs			
C_{eNB}	Capital cost for e Node B	400 €	[200,600] €
C_{EPC}	Capital cost for a single eNB	44 €	[22, 66] €
C_{eq}	DAS equipment	4760 €,	[2380, 7140] €
d	Number of DS	2 antennas/floor	[2, 200] antennas/floor
f_{st}	Site maintenance costs	0.8	0.8
c_{st}	Site costs	1240 €	[620, 1860] €
C_{run}	Running costs	357 €	[178.5, 535.5]€
C_{bh}	Backhaul costs for optic fiber	4800 €	[2400, 7200] €
BW	Backhaul bandwidth for a site's interconnection	10 Gbps	[5, 15] Gbps
f_{BW}	Backhaul bandwidth—expressed in €/Gbps	468 €	[234, 702]
C_{pw}	Energy consumption costs	63.08 €,	[31.54, 94.61]
C_{inc}	Implementation costs	1120 €	[560, 1680]

Algorithm 1 Experimental procedure

procedure MATHEMATICAL MODELS
  Calculate MIMO TCO
  Calculate DAS TCO
  Calculate modified DAS TCO

procedure PARAMETERS SELECTION
  Opt for the parameters for MIMO
  Opt for the parameters for DAS
  Opt for the parameters for modified DAS
  Opt for the price ranges

procedure SENSITIVITY ANALYSIS

  One way SA for the parameters:
$B, n, r, C_{st}, C_{run}, C_{bh}$
  Multi-way SA for the parameters:
M_s & M_d, C_{eNB} & C_{EPC} and BW & f_{BW}

DAS has already been thoroughly examined in [3, 4], where SA was conducted for all its parameters. In this study DAS is compared with the other deployments in terms of CAPEX, OPEX and TCO for the respecting number of antennas added in the suggested model.

Figure 3 indicates that CAPEX of the MIMO technology is the largest one especially for Massive MIMO scenarios. What is more, the DAS scenarios remain cheap especially for less than 1000 antennas added. The modified DAS model is the cheapest of all and its costs do not augment while the number of antennas increases.

Figure 4 indicates that OPEX of the MIMO technology is the largest one especially for Massive MIMO scenarios. What is more, the DAS scenarios remain cheap especially when the number of antennas does not exceed 1000. The modified DAS model is the cheapest of all and its costs do not augment while the number of antennas increases.

Figure 5 indicates that TCO of the MIMO technology is the largest one especially for Massive MIMO scenarios. What is more, the DAS scenarios remain cheap especially when the number of antennas does not exceed 1000. The modified DAS model is the cheapest of all and its costs do not augment while the number of antennas increases.

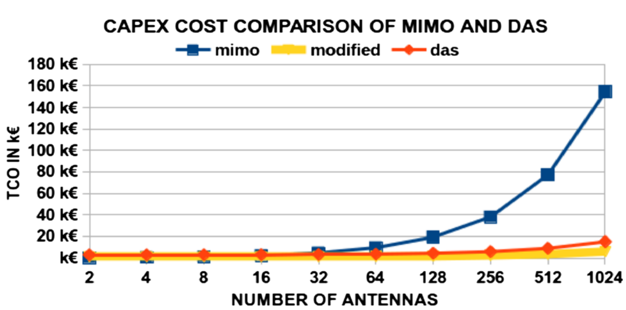

Fig. 3 The CAPEX costs of the alternative deployments

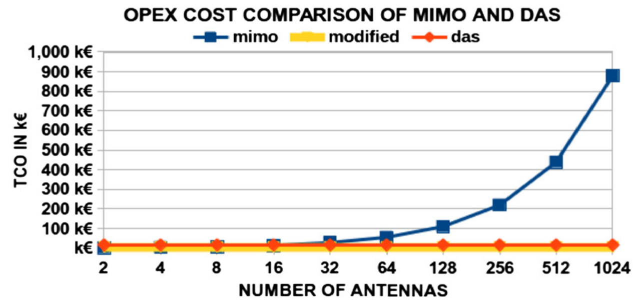

Fig. 4 The OPEX costs of the alternative deployments

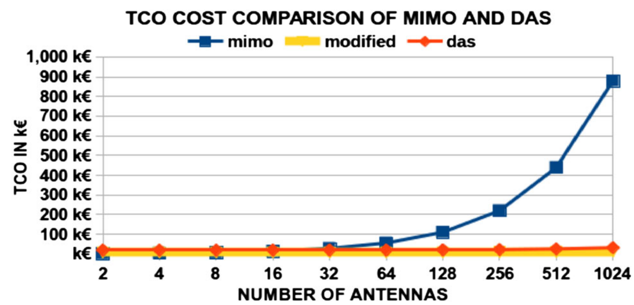

Fig. 5 The TCO costs of the alternative deployments

6.1 Modified DAS

The SA conducted for the modified DAS model is presented. There are several experiments indicating how the parameters are affected by the introduction of the virtualization techniques in the model are explained.

Figure 6 indicates that eNB costs affect the costs of the DAS model. They definitely affect the OPEX and therefore, the TCO, that are both proportional to th eNB. On the other hand, the costs are really diminished especially comparing them with the costs of the DAS before the introduction of the NFVs. Figure 7 indicates that EPC costs are not very important for the costs of the DAS model. They do not really affect the CAPEX, the OPEX or the

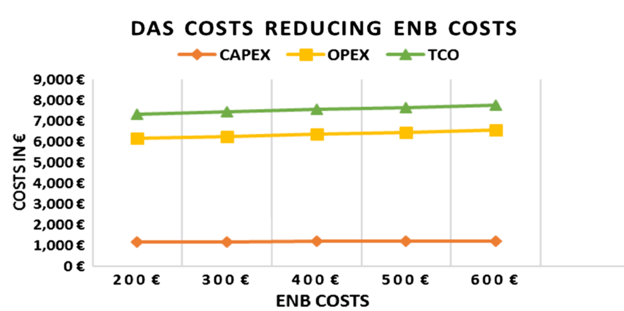

Fig. 6 The effect of the reduction of eNB costs on the modified DAS model

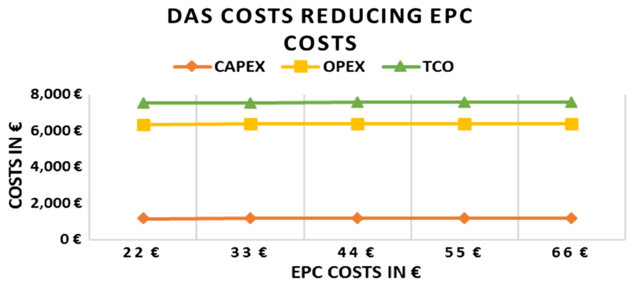

Fig. 7 The effect of the reduction of EPC costs on the modified DAS model

TCO, which almost remain stable. But, the costs are really diminished especially compared to the costs of the DAS before introducing the NFVs. Figure 8 indicates that BW costs do not affect the costs of the DAS model. They affect the OPEX and therefore, the TCO, that are proportional to the BW costs. On the other hand, the costs are diminished especially compared to the costs of the DAS before introducing the NFVs. Figure 9 indicates that equipment costs do not affect the costs of the DAS model. They do not affect the CAPEX, the OPEX or the TCO, which almost remain stable. But, the costs are diminished especially compared to the costs of the DAS before introducing of the NFVs. Figure 10 indicates that implementation costs are very essential for the costs of the DAS model. They affect the CAPEX and therefore, the TCO, that are proportional to the implementation costs. On the other hand, the costs are diminished especially compare to the costs of the DAS before the introducing the NFVs. Figure 11 indicates that site costs are very essential for the costs of the DAS model. They affect the OPEX and therefore, the TCO, that are proportional to the site costs. On the other hand, the costs are really diminished especially compared to the costs of the DAS before introducing the NFVs.

The SA indicates that DAS and modified DAS deployments have higher OPEX costs. OPEX includes all costs for running the system, the equipment, the day-to day costs, the power consumption costs etc. Therefore, it is of vital importance that these costs are diminished. Extra measures should be taken for the reduction of such costs. For

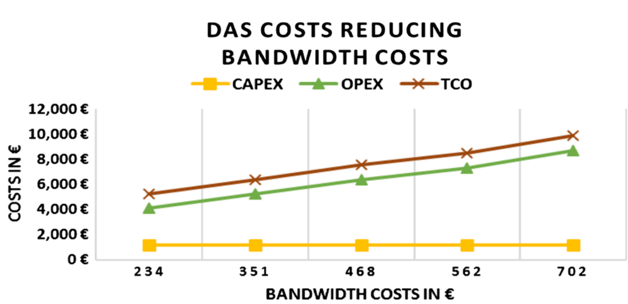

Fig. 8 The effect of the reduction of BW costs on the modified DAS model

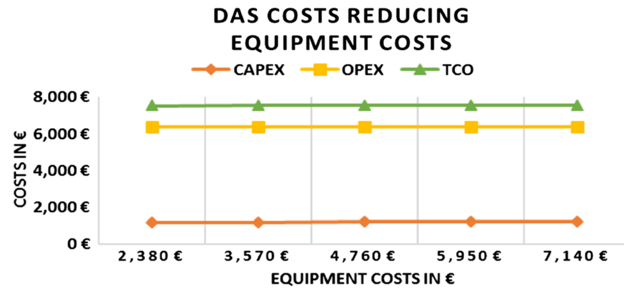

Fig. 9 The effect of the reduction of equipment costs on the modified DAS model

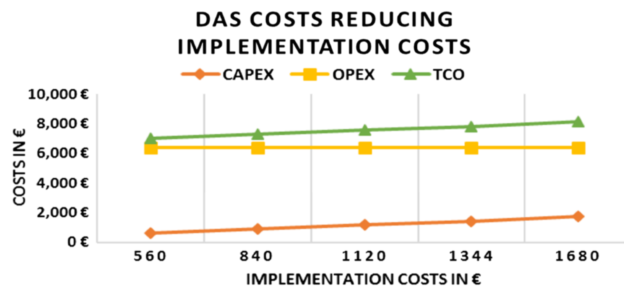

Fig. 10 The effect of the reduction of implementation costs on the modified DAS model

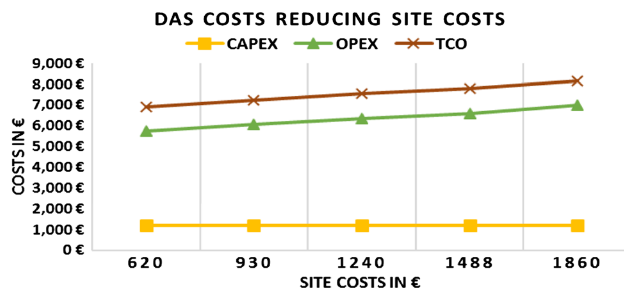

Fig. 11 The effect of the reduction of site costs on the modified DAS model

example, BW could be virtualized in order to be better used, managed and allocated. What is more, an optimized number of BS could be the answer to the augmenting costs. Operational and running costs are reduced if less hardware exist and less power/maintenance/support etc. are needed.

6.2 MIMO

SA summarizes the effect of the parameters on the MIMO models.

6.2.1 One-way sensitivity analysis

Figure 12 indicates that the number of the BS is very essential for the costs of the MIMO model. They affect the OPEX and therefore, the TCO, that are proportional to the number of the BSs. CAPEX remains in low levels, but is

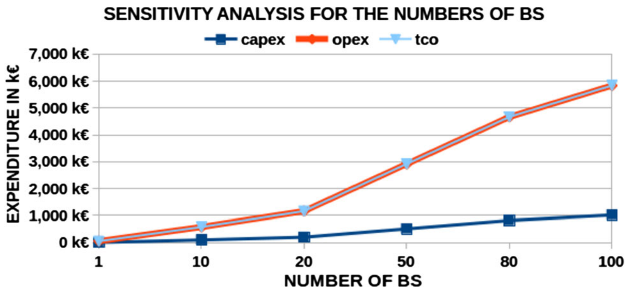

Fig. 12 The effect of the number of BS on the MIMO model

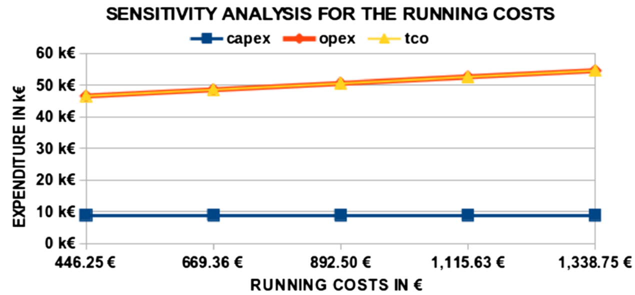

Fig. 14 The effect of the running costs on the MIMO model

still affected and linearly proportional to the number of the BSs. Figure 13 indicates that the costs for backhauling are very essential for the costs of the MIMO model. They affect the OPEX and therefore, the TCO, that are proportional to the backhaul costs. CAPEX remains in low levels for all the different prices of the backhauling. Figure 14 indicates that the costs for running the system are very essential for the costs of the MIMO model. They affect the OPEX and therefore, the TCO, that are proportional to the running costs. CAPEX remains stable for all the different prices of the backhauling. Figure 15 indicates that the site costs are not essential for the costs of the MIMO model. They do not affect the OPEX or the CAPEX, that remain stable for all the different prices of the siting costs. Figure 16 indicates that the interest rate is very essential for the costs of the MIMO model. It affects the OPEX and therefore, the TCO, that are proportional to the interest rate. CAPEX remains in low levels, but is still affected and linearly proportional to the interest rate. Figure 17 indicates that the years of the investment are very essential for the costs of the MIMO model. They affect the OPEX and therefore, the TCO, that are inversely proportional to the years of the investment. CAPEX remains in low levels, but is still affected and inversely proportional to the the years of investing.

The one-way SA shows that MIMO is strongly affected by costs related to running, backhaul, number of added antennas, interest rate and years of investment. These costs seem to be the most fundamental, when it comes to the viability of the model. What is more, it is also pointed out

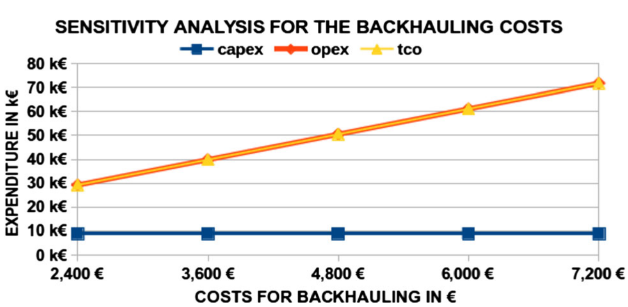

Fig. 13 The effect of the backhaul costs on the MIMO model

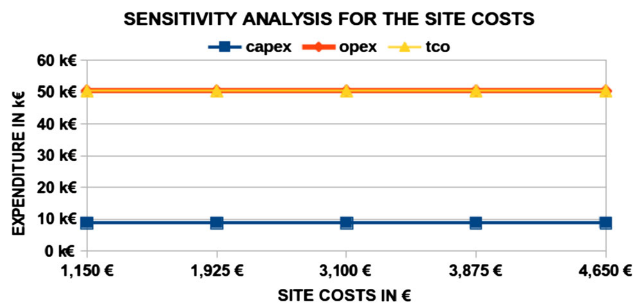

Fig. 15 The effect of the site costs on the MIMO model

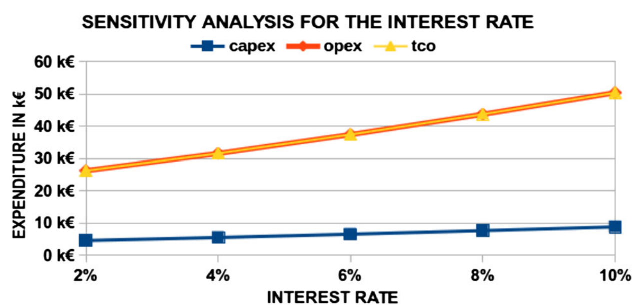

Fig. 16 The effect of the interest rate on the MIMO model

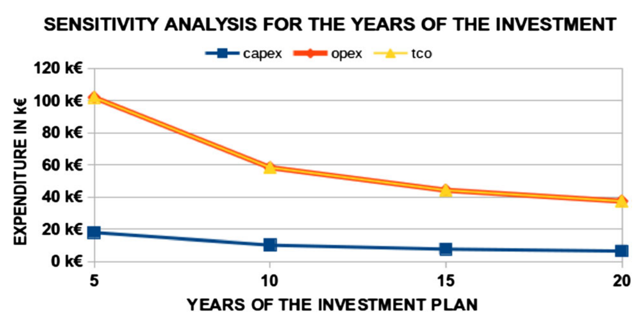

Fig. 17 The effect of the investment plan in years on the MIMO model

that the OPEX costs are the ones that burden the model. OPEX includes the running, maintenance and support of the system. Several important aspects should be considered so that costs made for the OPEX are diminished. As a result, costs for running and for power consumption could be reduced by introducing novel and more efficient technology in the system and also by substituting the hardware with software sources. Financial stability and lower interest rates contribute in lower TCOs and therefore, are also indispensable factors. Investing for more years is also money savvy, as providers actually have enough time to reciprocate from the technology.

6.2.2 Two-way sensitivity analysis

Figure 18 indicates that the BS costs are very essential for the costs of the MIMO model. They affect the TCO. When both parameters augment the TCO is augmented. Figure 19 indicates that the number of antennas are very essential for the costs of the MIMO model. They affect the TCO. When both antenna parameters augment the TCO is augmented. Figure 20 indicates that the BW costs are very essential for the costs of the MIMO model. They affect the TCO. When both parameters augment the TCO is augmented.

BW, BS and antennas are factors that affect very much the overall model and increase its TCO. Therefore, several measures as to whether these costs could be reduced should be taken into consideration. BW could be virtualized in order to be better used, managed and allocated. What is more, an optimized number of BS could be the answer to the augmenting costs. It is also important to pinpoint that for Massive MIMO deployments (namely where antenna numbers exceed the 64 antennas) it is obvious that the TCO costs become skyrocket. Therefore, it is of substantial importance to trace the optimal number of antennas on each side in order to gain the most fundamental advantages and also maintain the TCO and the individual costs in low levels.

7 Conclusions

The 5G demanding goals have raised a whole new era for the telecommunications. Current technological approaches seem to be inadequate and cost inefficient or can not meet these requirements. As a consequence, novelties need to be used in order to cover the brand new demands. Telecommunication operators and providers seek to obtain profits and augment their income although, investment in new technologies need to be made.

In this paper, two different technologies, namely the MIMO and DAS are examined from a techno-economic perspective. Both technologies include a number of antennas, which actually helps the better transmission of the signals, leads to better coverage and augmented network capacity, as well as is ideal for BW reallocation. DAS seems to be more cost effective especially, when NFVs are added to the DAS deployments, then the TCO become really lower and the total investment is worthy. On the other hand, MIMO also seems to be cost efficient, but for the Massive MIMO deployments costs high rocket and they become unbearable for the operators. Therefore, the optimized number of antennas needed on the source and destination is crucial and should be considered in the future.

When it comes to both deployments, NFV could be a nice option since less hardware, means also less power consumption costs, less operational, running and maintenance costs. Thus, research should focus in the direction of NFVs and how this technology could be introduced and implemented in future. What is more, power consumption seems to be an expensive factor for both deployments and several measures should be taken, research activity should focus on this direction so that power consumption is

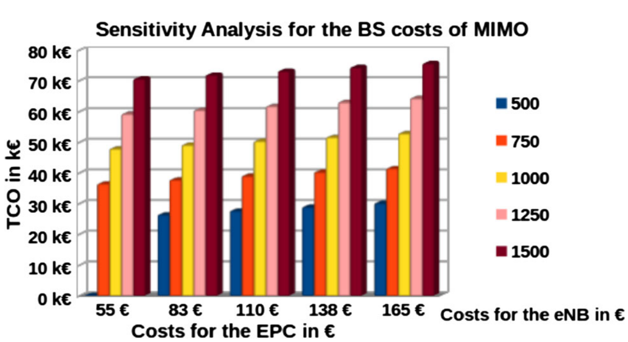

Fig. 18 The effect of the BS costs on the MIMO model

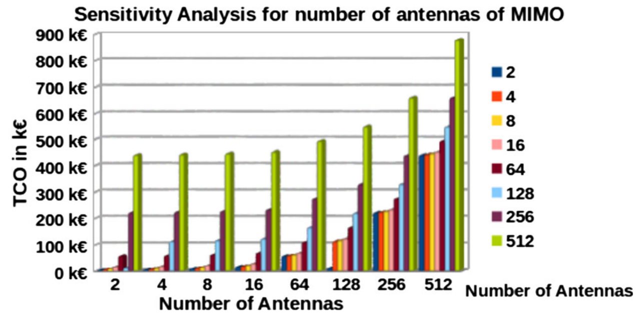

Fig. 19 The effect of the antennas on the MIMO model

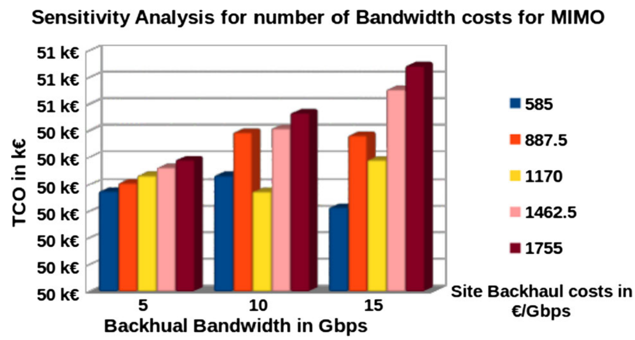

Fig. 20 The effect of the BW costs on the MIMO model

diminished for both technologies and 5G devices, BS, equipment.

While the advent of 5G is imminent several research questions are still open and should be investigated.

8 Future work

Future research activity should focus on novel ways of using the existing technologies and infrastructure, e.g. the usage of the NFV concept for older technologies. What is more, several ideas to optimize the power consumption and costs for back-hauling, bandwidth etc. should be introduced. Bandwidth sources could be virtualized and therefore, more cost efficient. Power consumption should be cut down on and therefore all the related costs will be limited.

Other types of costs, such as BS and DS also play a very important role in the cost formation. It is therefore substantial that research should focus on new ways of back-hauling, optimization methods for BS and DS, as well as on the optimization of the number of MIMO transceivers and receivers on each side. Finally, cost models should be presented for all the 5G key enabling technologies, so that it is concluded which factors influence the TCO of all the possible solutions.

References

1. Bouras, C., Ntarzanos, P., & Papazois, A. (2016). Cost modeling for SDN/NFV based mobile 5G networks. In *2016 8th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)* (pp. 56–61).
2. Bouras, C., Kokkinos, V., Kollia, A., & Papazois, A. (2015). Techno-economic analysis of ultra-dense and DAS deployments in mobile 5G. In *2015 International Symposium on Wireless Communication Systems (ISWCS)* (pp. 241–245).
3. Bouras, C., Kollia, A., & Papazois, A. (2016). Sensitivity analysis of small cells and DAS techno-economic models in mobile 5G. In *2016 IEEE Wireless Communications and Networking Conference* (pp. 1–6).
4. Bouras, C., Kollia, A., & Papazois, A. (2017). Dense deployments and das in 5G: A techno-economic comparison. *Wireless Personal Communications*, *94*(3), 1777–1797.
5. Passas, V., Miliotis, V., Makris, N., Korakis, T., & Tassiulas, L. (2016). Paris metro pricing for 5G hetnets. In *Global Communications Conference (GLOBECOM), 2016 IEEE* (pp. 1–6). IEEE.
6. Nikolikj, V., & Janevski, T. (2015). Incremental deployment aspects of beyond 4G and 5G mobile hetnets. *International Journal of Future Generation Communication and Networking*, *8*(6), 177–196.
7. Deng, N., Zhou, W., & Haenggi, M. (2015). Heterogeneous cellular network models with dependence. *IEEE Journal on Selected Areas in Communications*, *33*(10), 2167–2181.
8. Elmannai, W., & Elleithy, K. M. (2014). Cost analysis of 5th generation technology. International Society for Computers and Their Applications, Inc.
9. Ahokangas, P., Matinmikko, M., Yrjl, S., Mustonen, M., Posti, H., Luttinen, E., et al. (2014). Business models for mobile network operators in licensed shared access (LSA). In *2014 IEEE International Symposium on Dynamic Spectrum Access Networks (DYSPAN)* (pp. 263–270).
10. Khodashenas, P. S., Ruiz, C., Riera, J. F., Fajardo, J. O., Taboada, I., Blanco, B., et al. (2016). Service provisioning and pricing methods in a multi-tenant cloud enabled ran. In *2016 IEEE Conference on Standards for Communications and Networking (CSCN)* (pp. 1–6).
11. Gohad, A., Narendra, N. C., & Ramachandran, P. (2013). Cloud pricing models: A survey and position paper. In *2013 IEEE International Conference on Cloud Computing in Emerging Markets (CCEM)* (pp. 1–8).
12. Andrews, J. G., Buzzi, S., Choi, W., Hanly, S. V., Lozano, A., Soong, A. C. K., et al. (2014). What will 5G be? *IEEE Journal on Selected Areas in Communications*, *32*, 1065–1082.
13. Bouras, C., Kollia, A., & Papazois, A. (2017). SDN NFV in 5G: Advancements and challenges. In *2017 20th Conference on Innovations in Clouds, Internet and Networks (ICIN)* (pp. 107–111).
14. Yunas, S. F., Valkama, M., & Niemelä, J. (2015). Techno-economical comparison of dynamic DAS and legacy macrocellular densification. *International Journal of Wireless Information Networks*, *22*(4), 312–326.
15. Liu, Z., Kolding, T., Mogensen, P., Vejgaard, B., & Sorensen, T. (2012). Economical comparison of enterprise in-building wireless solutions using DAS and Femto. In *Vehicular Technology Conference (VTC Fall), 2012 IEEE* (pp. 1–5).
16. Senel, K., Björnson, E., & Larsson, E. G. (2017). Optimal base station design with limited fronthaul: Massive bandwidth or massive MIMO? Preprint arXiv:1709.05172. Accessed 17 Sep 2017.
17. Verde, F., Hong, Y.-W. P., Samardzija, D., Schober, R., & Tao, Z. (2012). Cooperative MIMO multicell networks. *EURASIP Journal on Advances in Signal Processing*, *2012*(1), 41.
18. Lim, Y.-G., Chae, C.-B., & Caire, G. (2015). Performance analysis of massive MIMO for cell-boundary users. *IEEE Transactions on Wireless Communications*, *14*(12), 6827–6842.
19. Muharar, R., & Evans, J. (2017). Performance analysis of massive MIMO networks with random unitary pilot matrices. Preprint arXiv:1709.03325. Accessed 11 Sep 2017.
20. Katsigiannis, M., Basaure, A., & Matinmikko, M. (2014). Cost comparison of licensed shared access (LSA) and MIMO scenarios for capacity growth in finland. In *2014 1st International Conference on 5G for Ubiquitous Connectivity (5GU)* (pp. 291–296). IEEE.

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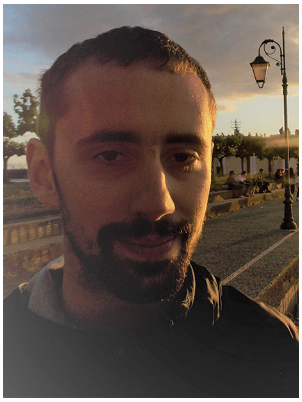

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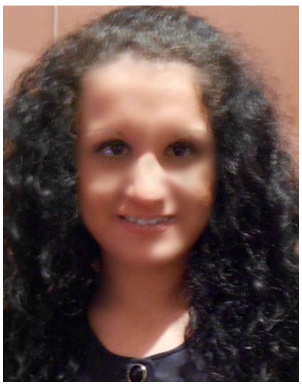

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