DAS Modifications for More Efficient Network Cost in 5G

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***Abstract*—Demanding goals have already been described concerning the next generation of mobile networks. In order to address these requirements, novel technologies are introduced or new concepts are integrated into conventional ones. In this paper, a modified Distributed Antenna System (DAS) architecture is described and a Sensitivity Analysis (SA) indicates which of the network cost parameters are the most influential ones concerning this model. Several hardware components are replaced with Network Function Virtualization (NFV) techniques, which are introduced, so as to contribute in reducing capital and operational expenses. The model is described mathematically, is compared and contrasted with the conventional model proposed by authors in past research activity. Simulation scenarios help concluding into fundamental results concerning the most dissuasive cost factors e.g. bandwidth, frequency, capacity, coverage, etc.**

Keywords*—*5G, pricing, cost models, mobile networks, Network Functions Virtualization (NFV), Distributed Antenna Systems (DAS)

I. INTRODUCTION

As 2020 approaches, 5G is becoming the most hot topic. Several technological concepts are proposed, so that 5G's exceeding expectations are met. Higher capacity, incessant coverage and gigabit data rates are only some of the promises made, which are going to be offered by the next generation of mobile networks. Economic crisis augments dangers for enterprises to invest in novel and efficient technologies. Advantageous solutions, that combine both high quality and low cost are indispensable. Several novel technologies, such as Network Function Virtualization (NFV) promise to contribute in this direction.

NFV enables the replacement of hardware parts and network functionalities with software. This approach helps reducing the Operational and Capital expenditures, while maintaining high standards. NFV helps reducing capital costs for servers, switches and sites, as virtualized parts occupy less space and limit all cost components. Day-to-day costs are reduced as less complicated devices that outcome from the introduction of NFV techniques, demand less resources, such as power, cooling or even human resources.

Distributed Antenna Systems (DAS) include a number of antennas within their structure. DAS is a conventional solution that is aged 30 years old. The need for incessant coverage in 5G networks has contributed to the fact that DAS is starring since 2013 in studies and market in the United States of America (USA).

5G is thoroughly examined in [1]. Several cost models of heterogeneous networks have been investigated in: [2], [3]. If the price per bit in 5G networks is diminished 1000 times, then the 5G costs could remain in today's levels [4]. Pricing models on cloud computing have been thoroughly investigated in [5]. Among other issues, [6] summarized the key technologies concerning the implementation of 5G and the most important requirements and expectations drawn by this generation of mobile networks. A techno-economic analysis of DAS in mobile 5G is described in [7]. The study presents an architectural model, it also contains a mathematical framework, that describes the contribution of all types of costs in the Total Cost Of Ownership (TCO). Parameters are opted for the Greek market considering the prices of 2015. Advancements of this work are proposed in: [8] and [9], where sensitivity analysis is used to predict the prices of all network components alongside with the viability of the proposed models in the next years, notably of 2020, when the advent of 5G is expected.

Dynamic DAS indicates superior performance especially in terms of coverage, Signal to Noise Ratio (SINR), network capacity and cost efficiency according to [10]. In this work, DAS is compared to macrocells. A system model and several assumptions are introduced, several experiments have been conducted to conclude to the previously mentioned ideas. Another DAS architectural framework is presented in [11]. Authors, have already presented cost models comparing DAS and femtocells in [7] concluding that if DAS Capital (CAPEX) and Operational (OPEX) expenditures were reduced, DAS could consist an important alternative for 5G. In [8] and [9] authors presented a sensitivity analysis including the parameters that play the most fundamental role into the cost formation. In [12] 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.

The ultimate goal of this study is to show that integrating novel technologies and concepts, such as NFV, it is probable that the costs of conventional technologies are reduced. Therefore, it will become easier and more economically viable to update the existing infrastructure with low budget.

The remaining part of this paper is structured as follows: In Section II the proposed architectures are analyzed and explained. In Section III the proposed financial and mathematical model is summarized. In Section IV the experimentation parameters are opted and thoroughly explained. In Section V several experiments concerning the models' viability are conduced. In Section VI conclusions are summarized and future research activity in the field is proposed.

II. PROPOSED MODELS

In this section, the architectural models proposed are explained and described.

A. Conventional DAS architecture

A DAS system contains several antennas connected in a specific medium and is capable of providing network services within a structure. It could be combined with existing wireless technologies. It contains many benefits, the most substantial of which are:

- higher spatial coverage
- scalability
- higher capacity
- low power consumption
- combination with other existing technologies, etc.

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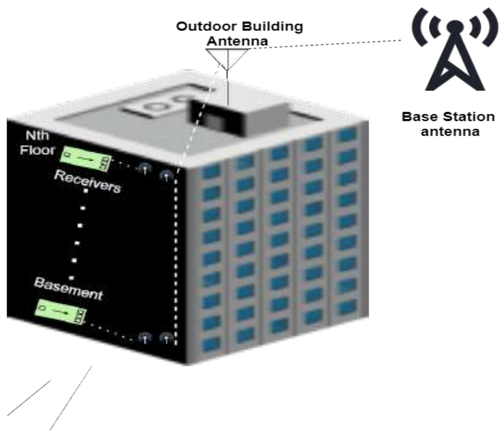

Fig. 1: A model for in-building conventional DAS architectures.

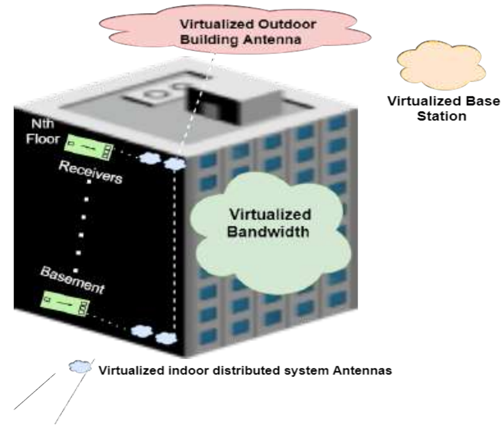

Fig. 2: A model for in-building modified DAS architectures.

There are two different kinds of DAS systems (indoors, outdoors). The one is used to cover in-building places and the other to cover outside areas. Although they are used in different spatial regions, their basic components remain the same. In order to cover the in-building demands that are raising nowadays, indoor DAS is a possibly applicable scenario.

A DAS system consists of two subsystems, namely the Distributed System (DS) and the Base Station (BS). The DS contains a number of antenna nodes, usually two antennas per floor of a building; one for the transmission and one for the reception of the Radio-Frequency (RF) signals and one feeder per downlink, that is used to cut down on the losses of the transmitters. Several transmitters are needed for the transmission of the information on both sides. The BS is a macrocellular-like BS, which receives and transmits. For the interconnection of all the components, a transmission medium is required. Optic fiber is preferred as the medium with the lower losses.

In a small building, that is underpopulated e.g. a block of flats, two antennas could be sufficient to cover a floor [9]. For a more populous place, such as an enterprise or an office infrastructure, several sets of antennas could be added on each floor. The system of every floor is connected to an outdoor antenna, usually located at the roof/top of the building. Several transceivers and feeders are used for the signal transmission. If the demands augment the DS infrastructure could be expanded adding several couples of antennas in the same floor. The aforementioned architecture as described in [7], [8], [9] and [11] and is depicted in Fig. 1. All the floor antennas communicate with the antennas at the top of the building, which communicates with the central BS.

B. Modified DAS architecture

The modified version of DAS will help reducing the most expensive costs. The idea behind this modification is that several parts of the equipment should be substituted with NFVs and more simplistic hardware. This tactic will reduce costs and will offer fundamental benefits. More specifically, the parts that are going to be virtualized are:

- Bandwidth
- Antennas
- Base Stations

Bandwidth is going to be virtualized and as a result, this fact is going to cut down on the bandwidth costs, as less bandwidth will be needed for covering all the infrastructure compared to the conventional DAS architecture. The cutting edge technology is a possible paradigm for on demand usage of bandwidth for the users. This approach leads to cloud friendly technologies. What is more, different wavelength could be available at once and therefore this fact could maximize the network's efficiency. Generalized Multi-Protocol Label Switching (GMPLS) technology could be used so that the network will become more intelligent.

Antennas could also be virtualized diminishing the costs for the antenna infrastructure as well as the costs for the distributed system. Base station components could be virtualized and contribute to cost reduction. Except for reducing the capital costs, these virtualized features offer another "side effect". Analytically, they contribute in limiting other costs as well, e.g. costs for the site acquisition, power consumption, running, operational costs etc., because the hardware is less complex consuming less power, less hardware will occupy less space and lower amounts of money will be required for operating and managing costs. Virtualized small antennas could be used taking advantage o the Channel State Information Reference Signal (CSI-RS) design, so that not only the costs for the antennas are reduced, but also the quality of the provided signal remains high.

The aforementioned architecture as described in [7], [8], [9] and [11] and after the integrating of all the virtualized components is described in Fig. 2. In this architecture, the bandwidth resources are better managed using virtualization techniques, antennas and base stations are substituted with virtualized ones leading to more flexible architectures.

III. Pricing Model

In previous research activity [9] a model for pricing DAS was proposed. In this model, all components of the formation of costs were considered in the analysis. Using the equation of the repeating payment, authors formed mathematical equations that calculate the costs for the DAS architectures.

In this equation, a loan is considered. The initial amount of money in the loan is denoted by P, that is repaid in an annual basis. A is the annual installment payment, r represents the periodic interest rate and n the years of payment.

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

The cost for the development of a DAS architecture is the Capital Expenditure (CAPEX). On the other hand, the cost for operating and maintaining the DAS architecture is Operational Expenditure (OPEX). A DAS system is mostly used in large coverage areas, as a result, it is most possible that a provider/operator has acquired such an infrastructure, so both costs are disbursed by the provider/operator.

In the following sections, the mathematical equations concerning the development and the maintenance of the DAS architecture, are formed and described thoroughly.

A. CAPEX

CAPEX cost represents the costs for acquiring new infrastructure, updating the existing one or the amendments that need to be made in existing components, when new ones are obtained. In a DAS system, the CAPEX includes costs concerning the Base Station (BS), the distributed system, back-hauling and also supplementary equipment e.g. supporting and monitoring equipment [11].

As mentioned before, BS costs contribute into the CAPEX. As a result, it is valuable to estimate the cost for a single node (eNB), which is the DAS BS unit. The DAS eNB is represented by the equation: $C_{eNB}+C_{EPC}$. Parameters C_{eNB} and C_{EPC} represent the costs for eNB and EPC respectively. C_{eNB} includes the costs related to the eNB equipment as well as costs for the site acquisition, back-hauling, construction, etc. C_{EPC} represents all the costs of the core network, for instance the cost of the core packet routers. Assuming that there are N BSs, the cost augments into: $N(C_{eNB}+C_{EPC})$. What is more, in order to form the actual costs, the 1 should be used as it should be calculated how much money should be given in an annual basis for the BS infrastructure. As a result, the BS costs are represented by the following equation:

$$C_{BS}^{CX} = N(C_{eNB} + C_{EPC})\frac{r(1+r)^n}{(1+r)^n - 1} \tag{2}$$

where r denotes the interest rate and n the installment years considered.

In addition, it is fundamental to include the distributed system's costs into the mathematical model. The costs for the equipment of the distributed system is denoted by the coefficient C_{eq}. The number of distributed structures is represented by another factor named d. The CAPEX for the distributed system per year is:

$$C_{DASEQ}^{CX} = C_{eq}d\frac{r(1+r)^n}{(1+r)^n - 1} \tag{3}$$

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

There is also another type of cost called Implementation Expenditure (IMPEX), which is the CAPEX needed for a moving the infrastructure into a different site. This includes all money spent on planning and installing a system as referred to [11]. It represents costs of installing all the subsystems, namely the BS and the distributed one, costs for coordinating etc. The variable C_{inc} describes these coordination costs, the costs for installing the distributed system and the adjusting activities, excluding the costs of the BS as they have already been considered.

As a result, the total CAPEX is the sum of all the individual costs, concerning the following equation:

$$C_{DAS}^{CX} = (C_{eq}d + N(C_{eNB} + C_{EPC}))\frac{r(1+r)^n}{(1+r)^n - 1} + C_{inc} \tag{4}$$

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

B. OPEX

OPEX includes all costs concerning the back-hauling and maintenance, the site renting, power costs, trouble-shooting, leasing costs, support etc. OPEX represents all actions that ensure the site's daily operation and maintenance. In order to address all these demands, a coefficient c_{run} is introduced. This factor represents all the costs for running a single site including several types of costs such as power consumption, support (in-site and off-site), maintenance. c_{bh} is a coefficient that represents all costs for back-hauling and the maintenance actions concerning it. The cost of all DAS BS on an annual basis is:

$$C_{BSDAS}^{OX} = N(c_{run} + c_{bh}) \tag{5}$$

The costs for the maintenance of the DS also contributes into the formation of the DAS OPEX costs. The C_{eq} coefficient represents the costs for one DS and d is the number of DS in the whole building. Therefore, the OPEX for the DS is given by:

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

Power is needed for the functioning of all the systems. As a result, the coefficient C_{pw} covers power bill's costs. The total bandwidth used is represented by a coefficient BW multiplied with a factor f_{BW}, which denotes the costs for back-hauling for this bandwidth. The f_{st} denotes the site maintenance costs. Therefore, the final equation for the yearly costs for the OPEX of DAS is formed as follows:

$$\begin{aligned} C_{DAS}^{OX} = N(c_{run} + c_{bh}) + f_{BW}BW + \\ + (f_{st} + C_{pw}C_{eq}d)\frac{r(1+r)^n}{(1+r)^n - 1} \end{aligned} \tag{7}$$

C. TCO

The total cost of owning a telecommunication system-architecture is the sum of all the individual costs that have to be paid on an annual basis. In this case, these costs include the CAPEX and OPEX. Analytically, considering the equations 4 and 7, the total cost per year for a DAS infrastructure is given by the following equation:

$$\begin{aligned} TCO_{DAS} = (N(C_{eNB} + C_{EPC}) + C_{eq}d(1 + C_{pw}) + f_{st}) \\ \frac{r(1+r)^n}{(1+r)^n - 1} + C_{inc} + N(c_{run} + c_{bh}) + f_{BW}BW \end{aligned} \tag{8}$$

The cost model is described below in Flow Chart 1. Cost calculation is split in three different steps. The CAPEX and OPEX are calculated and the resulting TCO stems from their sum.

IV. Parameters Selection

In this section, the parameters opted are explained and analyzed. All the parameters of the conventional DAS model are extracted by previous research activities ([8] and [9]) and are presented in Table I. The prices for all DAS components range between a minimum and a maximum price. This study is a provision of the network architectures regarding the advent of 5G. As a result, the prices' behavior are not known yet. 5G will be released in the future and all scenarios should be checked. Therefore, a provision of the prices in the years 2020 and beyond is needed.

In [8] and [9] sensitivity analysis was used to provide with all the possible pricing scenarios. As a result, a lot of different prices in the range of +/-50% were experimented with and led to many fundamental hypotheses. The principal prices were investigated about Greece concerning the time conducing the research. The same concept will be followed in this study as well, namely, the today's pricing is expanded diminishing prices from 40-80%, because virtualization is going to contribute so that all network components will cost less in the future and prices will be lowered up to 80%.

Algorithm 1 Cost model calculation

```
1:  procedure CAPEX CALCULATION
2:      Calculate amount A
3:      Calculate Base Station costs
4:      Multiply with number of Base stations
5:      Multiply with A
6:      Calculate distributed equipment costs
7:      Multiply with A
8:  return CAPEX=Add steps: (4), (7), implementation costs
9:
10: procedure OPEX CALCULATION
11:     Calculate operational expenses for Base Station
12:     Multiply with number of Base stations
13:     Multiply with A
14:     Calculate operational expenses for Distributed equipment
15:     Multiply with power consumption costs
16:     Multiply with site costs
17:     Multiply with A
18:     Calculate operational expenses for Bandwidth
19: return OPEX=Add steps: (13), (17), (18)
20:
21: procedure TCO CALCULATION
22: return TCO= Add CAPEX (8) & OPEX (19)
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On the modified model, specific components (antennas, bandwidth, BS) are replaced using virtualized techniques, thus costs for BS and DS equipment are cut down on drastically. According to the existing literature, the effect that virtualization has on the prices' diminishing is not determined either. In most studies, prices are claimed to be formed among 40% and 80% lower than the prices of the conventional technologies. In previous research [8] and [9] an extensive literature research has led to finding prices for Greece and European countries during the years 2015-2016.

In this research, it is supposed that 5G is going to be released in 2020 and as a result, a conformation of prices will be possible. The sensitivity analysis conducted shows how much the prices will raise or fall, assuming scenarios of 40-80% augmentation/reduction of the prices, integrating the reduction, in favor of the virtualization, the prices for the modified DAS components are calculated as a 40-80% price range of the today's prices and are presented in the Table I. In the sensitivity analysis of the network costs and components, prices are opted randomly in the price range selected as described. In the case of the sensitivity analysis of the CAPEX, OPEX and TCO prices are opted to be respective to the prices of the previous research activity [9], in order to have a common reference about the effect of the virtualization into cost formation.

Because of integrating NFV into the DAS, indirect advantages also appear. Specifically, NFV offers several other important benefits and drastically reduces costs related to: running the system, power consumption, site acquisition, IMPEX, etc. Less complex hardware leads to less power consumption and lower costs for maintenance and repairing. Therefore, related costs concerning power consumption, backhauling, running, maintaining, implementing are also reduced as less complicated programmable hardware replaces conventional hardware and expensive structures.

In Table I all the costs for the parameters of the modified DAS costs are presented with a fluctuation with a minimum and a maximum value of 40% to 80% respectively compared to the prices studied in [11].

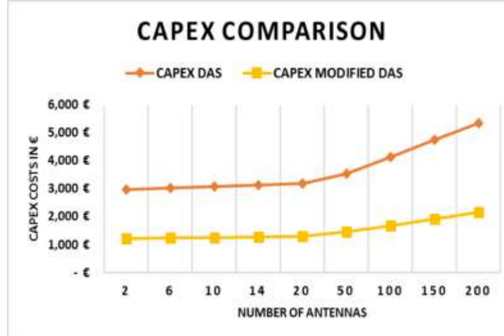

Fig. 3: Comparison of the annual capital expenditure for the DAS and modified DAS models.

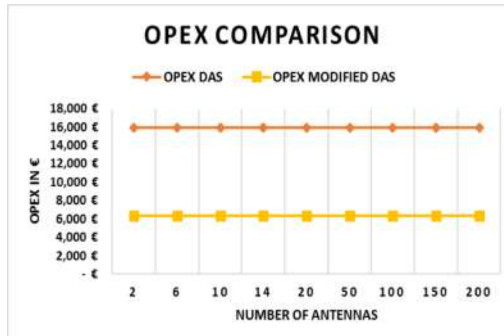

Fig. 4: Comparison of the annual operational expenditure for the DAS and modified DAS models.

V. EXPERIMENTAL PROCEDURE

In this section, the experiments concerning the proposed models are conducted. In order to compare and contrast the DAS and the modified DAS models, CAPEX, OPEX and TCO costs of the two models are depicted in figures. All these are experimented in Fig. 3, Fig. 4 and Fig. 5 respectively. In these experiments, costs are a function of the number of antennas needed for the DAS infrastructure. CAPEX and TCO are amounts augmenting in accordance with the number of the added antennas. On the other hand, OPEX is stable for both models. Observing the mentioned graphs, all kinds of expenditures are reduced in the modified model. Moreover, the number of antennas is used in order to have a common reference of the mentioned mathematical models. Thus, it is fundamental that for all types of costs the modified model is more efficient than the previous one.

In order to indicate the most fundamental benefits of the proposed model, a sensitivity analysis is held for all types of costs per variable that is affected by the replacement of the traditional parts with the new ones.

In order to indicate the impact that some cost parameters e.g. base station costs, equipment, antennas, power consumption etc. have on the CAPEX, OPEX and TCO. So, the figures, that are going to be presented are in terms of cost in function of the cost parameters opted for the sensitivity analysis.

Fig. 6 is presenting all types of costs in relation to the backhaul bandwidth. The CAPEX is not affected by this price reduction. OPEX and TCO are really affected. This is normal as bandwidth is rented and money are withdrawn for its acquisition every year and as a result, it consists an operational expense. Fig. 7 and 8 are presenting costs of the base stations. These types of costs are not dramatically reducing the overall

TABLE I: DAS Cost Parameters and Values.

Parameter	Description	Conventional DAS values	Modified DAS values	DAS values 2017
C_{eNB}	Capital cost for e Node B	[500,1500] €	[200,600] €	1000 €
C_{EPC}	Capital cost for a single eNB	[55, 165] €*	[22, 66] €	110 €
N	Number of the DAS BS	1	1	1
r	Periodic interest rate	[2, 20]%	[2, 20]%	6%
C_{eq}	DAS equipment	[5950, 17850]	[2380, 7140] €	11900 €,
d	Number of DS	[2, 200] antennas/floor	[2, 200] antennas/floor	2 antennas/floor
f_{st}	Site maintenance costs	0.8	0.8	0.8 €
c_{st}	Site costs	[1550, 4650] €	[620, 1860] €	3100 €
C_{run}	Running costs	[446.25, 1338.75]€	[178.5, 535.5]€	892.50 €
C_{bh}	Backhaul costs for optic fiber	[2400, 7200] €	[2400, 7200] €	4800 €
BW	Backhaul bandwidth for a site's interconnection	[5, 15] Gbps	[5, 15] Gbps	10 Gbps
f_{BW}	Backhaul bandwidth – expressed in €/Gbps	[585, 1755]	[234, 702]	1170 €
C_{pw}	Energy consumption costs	[78.84, 236.54] €	[31.54, 94.61]	157.68 €
C_{inc}	Implementation costs	[1400, 4200] €	[560, 1680]	2800 €

*: Included in the above cost.

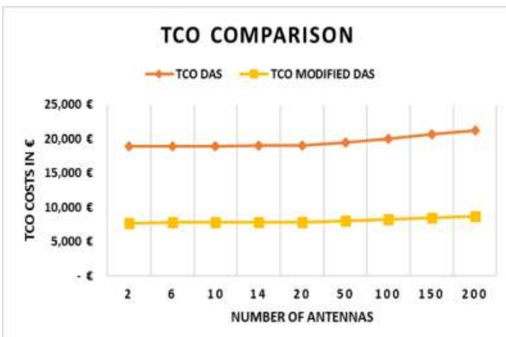

Fig. 5: Comparison of the annual total expenditure for the DAS and modified DAS models.

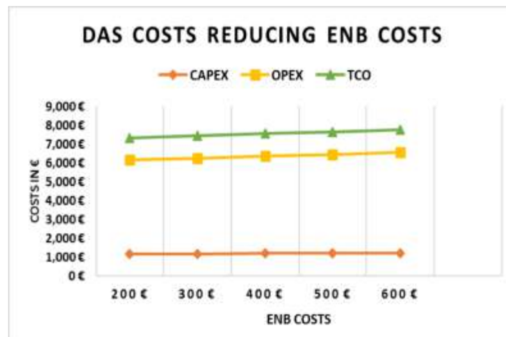

Fig. 7: Effect of eNode B C_{eNB} costs of the capital, operational and total expenditures for the modified DAS model.

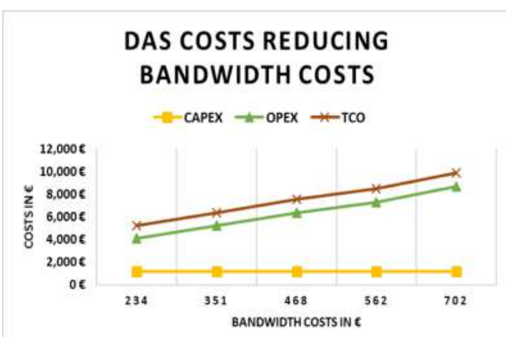

Fig. 6: Effect of bandwidth f_{BW} costs of the capital, operational and total expenditures for the modified DAS model.

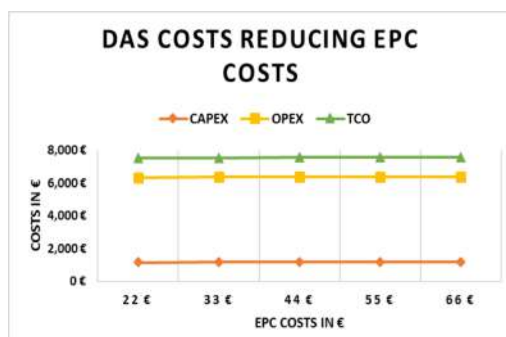

Fig. 8: Effect of EPC C_{EPC} costs of the capital, operational and total expenditures for the modified DAS model.

costs of the modified DAS implementation. Comparing it to the conventional DAS' expenses, the cost of this parameter also contributes in reducing the costs of the DAS implementation. As components become simpler, their implementation is easier and less expensive. The base station costs are reducing the overall CAPEX, because most base station costs are paid during the process of the networks' implementation.

Fig. 9 is presenting all types of costs in relation to the costs for the DAS equipment (antenna structures). These types of costs are not dramatically reducing the overall costs of the modified DAS implementation. Comparing it to the conventional DAS' expenses, the costs of the previous parameters are reduced. The costs for the establishment of the DAS equipment is reducing the CAPEX, because antenna infrastructure is paid during the process of the networks' implementation. Fig. 10 is presenting all types of costs in relation to the costs for the DAS implementation (installation and coordination). These types of costs are drastically reducing the CAPEX, when they are

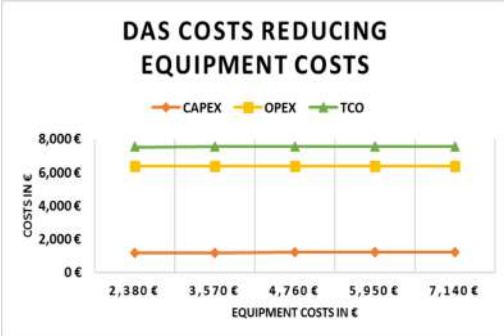

Fig. 9: Effect of equipment C_{eq} costs of the capital, operational and total expenditures for the modified DAS model.

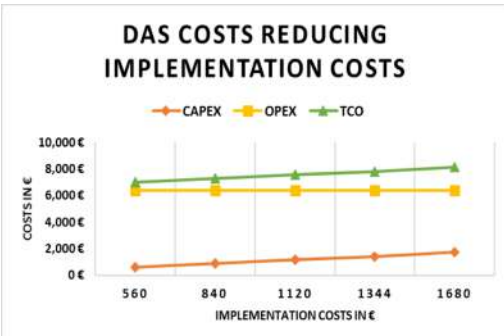

Fig. 10: Effect of implementation C_{inc} costs of the capital, operational and total expenditures for the modified DAS model.

diminished. This is normal as implementation costs are related to the capital expenditures, as they represent costs paid for coordinating and installing new infrastructure. Comparing it to the conventional DAS' expenses, the cost of this parameter also contributes in reducing the costs of the DAS implementation. Fig. 11 is presenting all types of costs in relation to the costs for the DAS site. These types of costs are drastically reducing the OPEX and the overall costs of the modified DAS implementation, when they are reducing. Site costs are related to the operational expenditures, because they represent costs that are paid for modifying the site of the infrastructure. Comparing it to the conventional DAS' expenses, the cost of this parameter also contributes in reducing the costs of the DAS implementation as DAS occupies less space and as a result, site costs are diminished.

VI. Conclusions & Future Work

In this section, the main conclusions are summarized and future research activity in the field is proposed. The modified DAS scenario is absolutely important, because compared to results of [8] for the same network the prices are really lower and the ideas introduced help succeeding in providing a cheap and yet efficient solution. It is therefore hoped that DAS will become a feasible idea in the future. 5G is setting its goals and novel technologies or new concepts introduced to the conventional ones could contribute in providing efficient architectures, that will support IoT or M2M communications, but on the other hand, will keep costs low. Therefore, virtualization seems to be an ideal concept to this direction.

Future research activity should focus on several ways and technologies that could help enhancing mobile and wireless networks quality of service and experience, coverage and

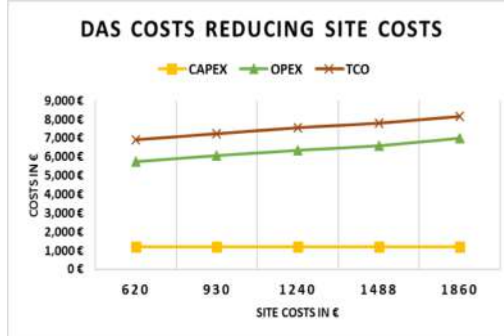

Fig. 11: Effect of site C_{st} costs of the capital, operational and total expenditures for the modified DAS model.

performance keeping its implementation and function costs low. Novelties, such as NFV and Software Defined Networking in combination with conventional technologies could help succeeding in this direction especially with the imminent advent of 5G. Special considerations should be analyzed when it comes to performance, efficiency and cost.

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