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Analyzing Small-Cells and Distributed Antenna Systems from Techno-Economic Perspective

Christos Bouras, Computer Technology Institute and Press “Diophantus”, Patras, Greece & Computer Engineering and Informatics Dept., University of Patras, Patras, Greece

Vasileios Kokkinos, University of Patras, Patras, Greece

Anastasia Kollia, University of Patras, Patras, Greece

Andreas Papazois, University of Patras, Patras, Greece

ABSTRACT

The new generations of mobile networks will require economical and viable solutions in order to meet the promises raised by scientists. In this article, the authors overview the available research activities and present an architecture for DAS and femtocells and a mathematical model analyzing their costs, as they are considered technologies, that offer great advantages for mobile networks. The authors present a wide research in the solutions’ parameters and prices. There are thorough experiments including several different types of costs. In particular, Capital (CAPEX), Operational (OPEX) expenditures and Total Cost of Ownership (TCO) are examined for both technologies in terms of the backhauling technologies, of the size of buildings that they are implemented in and the years of investment from a telecommunication company. The main results are that femtocells are a more appealing solution when it comes to small places, while the alternative is more favorable for big infrastructures.

KEYWORDS

5G, DAS, Femtocells, Small-Cells, Techno-Economic Analysis, Ultra-Dense

1. INTRODUCTION

Next-generation of mobile technologies is expected to largely augment the system’s peak data rates and cut down on the round-trip delays. The main idea of using ultra-density or DAS (Distributed Antenna Systems) based on their properties, is that they are able to increase efficiency and expand network capacity without the need for more spectrum resources by redistributing the existing ones, depict them as the key solutions for the future mobile networks. Small cells and DAS were launched mainly for addressing the issue of limited connectivity indoors.

There are several other important benefits of these technologies, which constitute them as bases for future generations of mobile networks, such as 5G (5G-PPP, 2014). Femtocells’ benefit is that they provide ultra-density, which is expected to be one of the essential features of 5G. Ultra-dense networks coexist with the existing macrocellular ones forming altogether heterogeneous networks and fulfill the requirements and the network’s future demands. Scientists and researchers have decided to move towards this direction by conducting research activity in the area (Networld2020 ETP, 2014; IWPC, 2014).

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The future mobile networks are going to demand a large network coverage. DAS would be an ideal solution to deal with the limited spectrum, because it provides repeaters, that are connected to the antenna system. It also serves the augmenting numbers of the smart devices, that in the future will be connected to the Internet or the smart home devices of the owner's home network as we move dynamically to the Internet of Things.

This paper studies the techno-economic aspects of ultra-dense and DAS deployments. It presents the characteristics and advantages for all their parts, as well as a techno-economic modeling of these deployment types. The defined models are used for the investigation of the upper technologies from an economic point of view. They provide an insight in the future financial and pricing aspects of these solutions and consist a useful tool for the definition of financing and pricing policies towards economically viable deployments. The authors define models for selecting the most appropriate network architectural solution for public buildings' indoor coverage. Cost, investment, materials, coverage and capacity are the parameters that are taken into account for the definition of their models. The main scientific contribution of this paper is that it includes multiple case-study examples of the techno-economic models as well as results of conducted experiments. It also analyzes and presents a techno-economic model and summarizes the main research activity in the particular field.

The remaining part of this paper is structured as follows: the second section refers to the related research that has been conducted so far. The third section presents the architectures of ultra-dense and DAS deployments used in the models. In the following section we describe cost models for ultra-dense and DAS deployments. In the next section we define the parameterization of the cost models. In the sixth section we conduce some experimental scenarios and analyze the corresponding results. Finally, in the seventh section we conclude our paper with the most fundamental conclusions realized in the experimental procedure and in the final section we list some ideas for future research work in the field of mobile network technologies.

2. RELATED WORK

In this section, it is of major importance to present the most valuable studies that have been conducted in the field. The record of the most valuable past research activity is going to indicate the paths that future scientific research should follow describing mobile network deployments.

In literature, the DAS system's most valuable studies are (Liu, 2013; Liu et al., 2012), that examine technological and economic aspects of the technology and compare the Total Cost of Ownership (TCO) between DAS and femtocells, leading to the fact that femtocell deployments are cheaper than the DAS ones. There are not any other vital studies in the field of DAS deployments, so it is important to point out the need of investigating it.

There exists substantial activity in the field of small cells. Scientists have already studied the technological aspects, such as cognitive radio, self-organized networks, and radio resource management leading to a significant technological background. Literature review is indicating that techno-economic aspects of small cells have not been fully researched, although there are fundamental works that have been published so far, like (Shetty et al., 2009) that refers to the economic advantages that stem from the combination of the macrocells and the femtocells for the operator and (Claussen et al., 2007) that adequately investigates the cost of the network for the predecessor of femtocell, the picocell. Scientists, but mostly the telecommunication and network operators are interested in the techno-economic aspects. Similar works like the one described in (Nikolikj et al., 2014) examine several deployment strategies from a cost perspective.

The authors of this paper have also presented an introduction to the present work in (Bouras et al., 2014), where they analyze models for financing and pricing small cell and macrocell service and compare which case is the most favorable from the perspectives of users and operators. (Markendahl et al., 2010) compares the two main technologies macrocells and femtocells conducting important conclusions for the costs whether or not a new base station is formed. According to this research, if a base station is needed, then the macrocells remain an effective alternative. The (Fratu et al., 2014) refers to a purely technological analysis of the femtocell technology, analyzing the interference, energy efficiency and spectrum efficiency in heterogeneous networks. The techno-economic analysis (Yunas et al., 2014) presents a thorough investigation of small cells, microcells and macrocells by taking into account factors, such as the coverage, the capacity, the energy and the cost efficiency. The research ends up concluding that ultra-density is the main key to 5G. In (5G-PPP, 2014; Networld2020 ETP, 2014) are discussed the underlying demands of the advent of 5G. The most important demands of 5G are augmented network capacity, more coverage, better redistribution of the available resources, safer network connection etc.

3. ALTERNATIVE DEPLOYMENTS

In this section, we analyze the most valuable characteristics, that small cells and DAS deployments present and depict their basic structures:

3.1. Small Cells

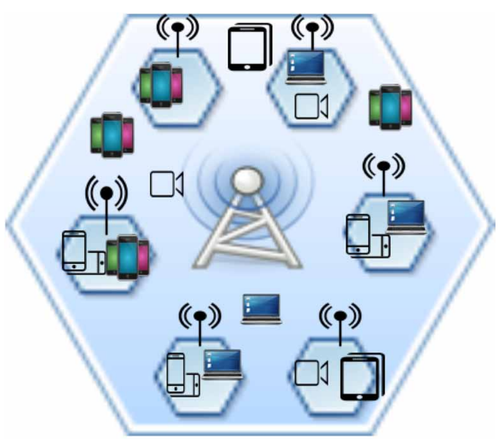
According to NetWorld 2020 in (Networld2020 ETP, 2014), 5G mobile networks should also prioritize the provision of methods for flexible pricing mechanisms and small cells constitute a suggestion that offers many possibilities. In parallel, the International Wireless Industry Consortium (IWPC) stresses the vitality of ultra-densification in next generation of cellular systems, i.e., the 5G systems (IWPC, 2014). It is considered that ultra-densification Figure 2 is the fundamental requirement that 5G systems should meet in order to achieve fundamental requirements, such as:

- 50x times more capacity (competent spectral efficiency, wider available spectrum) (IWPC, 2014).
- Peak data rates exceeding 10Gbit/s.
- Ultra-low latency below 1msec.

These types of deployment are expected to become extremely efficient, when they are addressed in places where traffic patterns are high as described in Figure 1.

Ultra-density offers many significant benefits for subscribers and mobile network operators. One key evolution in mobile networks is the shift from cells offering large coverage to progressively

Figure 1. The proximity of the cells in Ultra-dense deployments



smaller cells, and ultimately leading to super-dense deployments. Ultra-density brings base station next to the mobile device. Subsequently, it offers the following benefits to end-users:

- Higher throughput as well as lower round-trip delays.
- Improvement in indoor coverage due to internal base station deployment.
- Seamless hand-offs from outdoors (macrocellular access) to indoors (small cell access) and vice versa.
- Closed user group accessibility. On the contrary, to the open user group access, enables the choice of pre-decised group of users or devices that will access a particular cell.
- Stricter security protocols and algorithms.

Additionally, apart from customers' satisfaction, there are several important benefits for the mobile telecommunication operators. The most fundamental ones are the following:

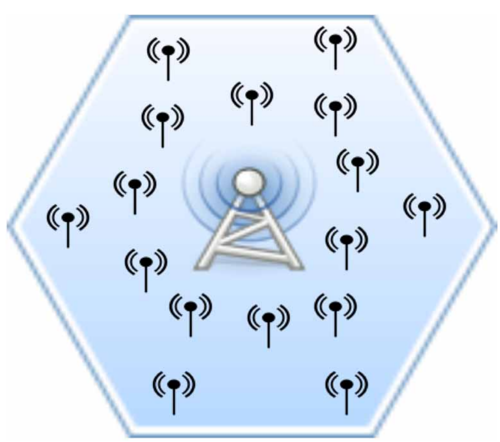
- Lower expenditures for obtaining the basic assets and for the operation of the system.
- De-congestion of the macrocell network by reusing spectrum from the small cells perspective.
- The spectrum redistribution augments the network's capacity.
- Power consumption and energy costs diminish, because small cells are well-known for being a green technological solution.
- Degrade problems and issues of law and administration that arise from the macrocells' use.

Ultra-density has several significant benefits for both subscribers and mobile network operators that make it an appealing service and a solution that compete successfully against the conventional solutions. Subscribers interfere without special knowledge in the terminal of small cells. Another important problem solved by the adoption of the microcellular technology is the one of the handovers. Small cells are more secure compared to other solutions, because they offer the possibility to limit the access permissions within a preselected group.

On the other hand, there are several challenges that ultra-dense deployments face. Based on the analysis presented in (Fratu et al., 2014), they are summarized as follows:

- Self-organizing network features, since operators will not be able to perform conventional network planning over ultra-dense deployments.

Figure 2. There are many antennas and cells inside the coverage area of a bigger cell in Ultra-dense deployments



- Inter-cell interference, because of the existence of the femtocell tier over the existing macrocellular infrastructure.
- Energy efficiency features, since the total energy consumption will be likely to increase.
- Spectral efficiency features, which will enable the high re-usage of the available spectrum resources.
- Cost efficiency, which is not only a technical challenge but also, is the main topic of this paper.

3.2. DAS

Another possible solution in order to augment the number of users connected to the network is the use of a DAS deployment. DAS Figure 3 is a network of spatially separated antenna nodes connected via a common source via a transport medium that provides wireless service within a structure. There are several assets in the usage of DAS related to more efficient coverage, lower power consumption etc. A typical DAS consists of the following components:

- A number of remote DAS nodes, each one includes at least one antenna for the transmission and one for the reception of wireless provider's Radio Frequency (RF) signals (2 antennas). This structure is equivalent to the existing conventional antenna, but in this case, its functionality is parted in smaller antenna structures. There is also a great need in supporting assets and equipment, such as amplifiers, remote radio heads, signal converters and power supplies.
- A high capacity signal transport medium. The desired medium is fiber optic cable, because does not incur signal loss unlike other cheaper means of transmission.
- A great variety of radio transceivers, that process and control the transmitted signal.

A basic structure includes two antennas and two feeders per floor. The case of indoor DAS is implemented inside buildings and includes all the components mentioned. In each down-link exists a passive feeder. If the number of devices served augments, more than one structures in every floor are introduced. DAS technology also has several significant benefits for both subscribers and mobile network operators that make it an appealing solution such as:

- Better defined network coverage and redistributed capacity.
- Many coverage holes that enable networks to overcome the capacity problems.
- Offering of the same coverage, but less power consumption compared to other solutions.
- The distributed antennas are not placed in such high altitudes as the equivalent single ones.

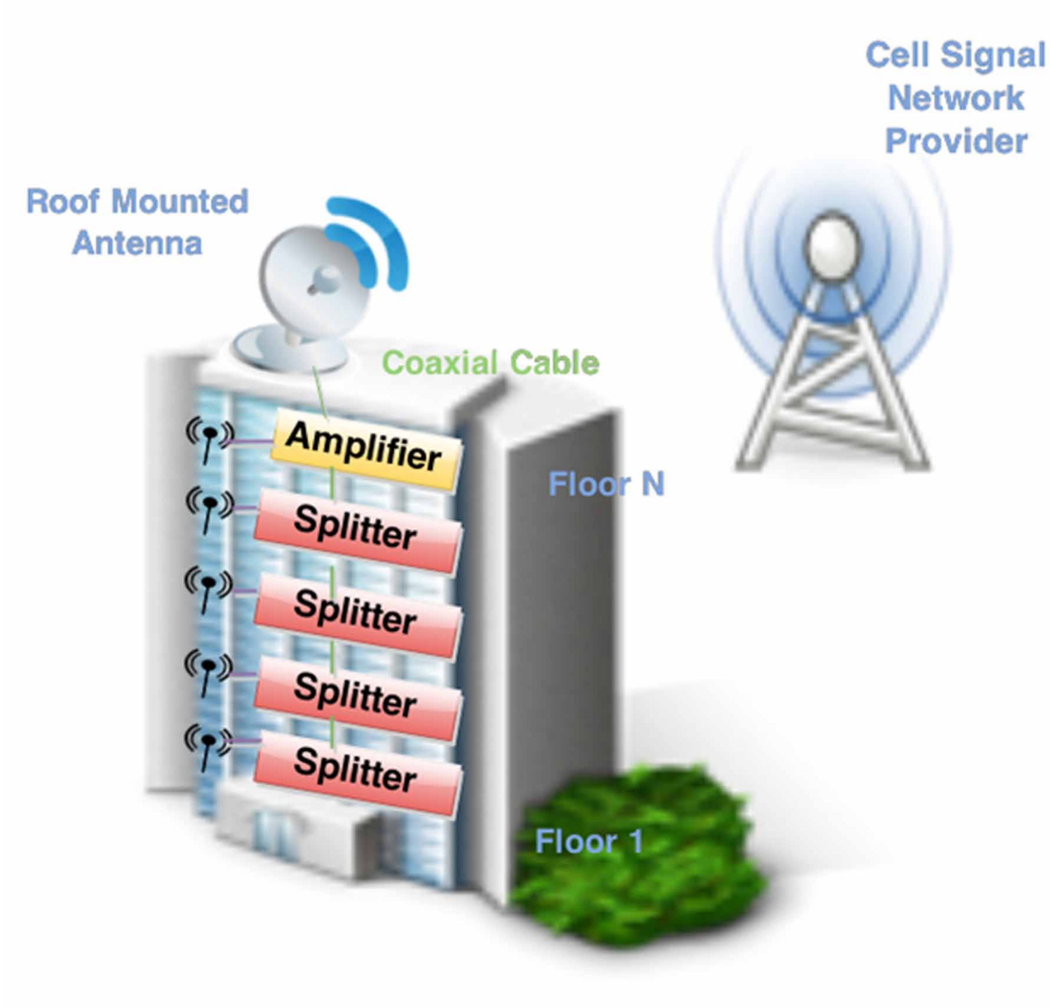
On the other hand, some of the issues raised by DAS opponents are the following:

- High costs, due to the additional infrastructures, that have already been referred.
- Possible health concerns, due to greater visual impact on users.
- Different network design than the microcellular solutions.
- Expertise for engineers for designing and maintaining the network.

4. COST ANALYSIS

In this section, it is of vital importance to mathematically assess the costs of the previous technologies. We propose three financial models that are used for the cost estimation of the technological cases presented below: small cells, macrocells and DAS.

Figure 3. Description of the DAS system architecture of a building



4.1. Methodology

For the two basic types of deployment for macrocells and small cells, we assume two types of costs the capital (CAPEX) and the operational expenditure (OPEX). The CAPEX is the amount of money a network operator spends in order to obtain new equipment, sites, etc. On the other hand, the OPEX sums the expenditures that are related with the costs that occur during the whole year and cover the budget needed for maintenance and operation. Previous studies, have adopted a united pattern of computing these costs and have followed the same reasoning. The methodology is presented in (Claussen et al., 2007), that points out how important is to estimate the CAPEX and OPEX annually. CAPEX is foreseen for the new equipment by using an important assumption. CAPEX is considered to be a loan, so CAPEX is valued as the capital that is acquired through the loan. Finally, the annual payments for the installation and deployment of the new equipment are the budget needed to repay the loan.

Generally, it is possible to make an assumption over the loan of a principal amount P, which should be repaid annually. The money needed to be repaid is presented by the annual installment payment, represented by A and is expressed by the repeating payment type:

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

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

4.2. Ultra-Dense Deployment

In this section, we analytically present the costs that bear a subscriber or an operator that chooses to implement the ultra-density in a network and it is important to present the two cases of expenditures of ultra-dense deployments.

4.2.1. Capital Expenditure

The CAPEX is described as expenses that stem from the base station and the routers needed to control the network's traffic. There is also a type of cost that is related with the core network of the mobile operator. These costs are the most expensive ones, this is why we do not consider other cheaper expenses, such as the cost for the Evolved Packet Core (EPC). Furthermore, we assume that there already exists a mobile network operator that provides a broadband connection. Thus, we do not include in our analysis the costs for the broadband equipment and the backhaul equipment. The CAPEX, based on the hypothesis in (1) and as soon as, the base station cost is represented by C_{HeNB} and the cost of the interface needed for the management of the network is represented by $C_{i/f}$, then the annual cost for the installment of an ultra dense deployment, which consists of N HeNBs is described by the following equation:

$$C_{dense}^{CX} = \frac{\mathrm{i}NC_{i/f}}{1-\left(1+i\right)^{n}} \tag{2}$$

C^{cx}_{dense} denotes the annual total cost of CAPEX and N is the number of HeNBs.

$$C_{dense}^{CX} = N\left(C_{HeNB} + C_{i/f}\right)\frac{r\left(1+r\right)^{n}}{\left(1+r\right)^{n-1}} \tag{3}$$

C^{cx}_{dense} denotes the annual total CAPEX and N is the number of eNBs consisting the ultra-dense deployment.

4.2.2. Operational Expenditure

OPEX does not include the expenses presented below:

- Site leasing cost is ignored given that the base stations are installed in the subscriber's property, so it is of the user's point to pay the costs.

- Power consumption is negligible, due to small cell size and environmentally-friendly features and is paid by the subscriber.
- Support and maintenance costs bare mainly the broadband service provider as well as the subscriber. The small cell is acquired by the subscriber, so if damaged, he is obliged to replace it.

Consequently, only one cost category is considered in the OPEX for the ultra-dense deployment and is the cost for the equipment of routing management of the network. Maintenance costs are considered linearly proportional to CAPEX and are calculated as CAPEX multiplied with a coefficient $f_{st,}$ that denotes bandwidth and site costs due to maintenance activities. Subsequently, OPEX is represented by the following equation:

$$C_{dense}^{OX} = f_{st} N C_{i/f} \frac{r\left(1+r\right)^{n}}{\left(1+r\right)^{n-1}} \tag{4}$$

Consequently, the following equation:

$$C_{dense}^{TCO} = \left(1+f_{m}\right)\frac{\mathrm{i} N C_{i/f}}{\left(1-i\right)^{n}} \tag{5}$$

where C^{TCO}_{dense} expresses the TCO for small cell deployment that bears the mobile network operator's side on an annual basis. This expression is based on (2) and (3) and it should be reminded that i is the interest rate and n is the duration of the installment plan in years.

4.3. Macrocellular Deployment

In this subsection, we present the basic costs that are included in a macrocellular deployment. In this case also, the macrocellular costs are split in the two same sides as previously.

4.3.1. Capital Expenditure

It represents the costs that are made in order to expand the core EPC network. Assuming that these costs are expressed by C_{eNB} and C_{EPC} respectively, the amount of money needed for one base station is given by the expression: $C_{eNB} + C_{EPC}$. It is significant to estimate the cost of a single evolved Node-B (eNB), namely the macrocellular base station. It consists of the network equipment, so we assume CAPEX is represented by the network base station costs, because it fully covers the eNB and the Evolved Packet Core (EPC). For that reason, the cost is described by the following expression: $C_{eNB} + C_{EPC}$. The amounts C_{eNB} and C_{EPC} are the costs for eNB and EPC, which is the term used for Long Term Evolution (LTE-A)'s core network, respectively. It is important that the C_{eNB} apart from the costs related to the eNB equipment and implementation, also includes any additional costs for the site acquisition, construction and eNB's backhaul. The amount C_{EPC} includes all the costs related to the core network, such as costs occur for routing the network's traffic.

Usually, the macrocellular deployment consists of several base stations, the number of macrocellular base stations existing is represented by the coefficient N, that is computed in numbers of base stations, then the total cost for all the base stations is given by: $N(C_{eNB} + C_{EPC})$.

If we presume that the CAPEX for the macrocellular deployment is an investment amount $N(C_{eNB} + C_{EPC})$ that has to be made in advance, then based on the basic assumption (1) we can form the following equation for the macrocellular CAPEX:

$$C_{macro}^{CX} = N\left(C_{eNB} + C_{EPC}\right)\frac{r\left(1+r\right)^{n}}{\left(1+r\right)^{n-1}} \tag{6}$$

where C^{cx}_{macro} denotes the annual total cost of CAPEX.

4.3.2. Operational Expenditure

c_{run} is a coefficient, that represents the total annual costs for running a unique site providing the costs for power, in-site and off-site support, in-site and off-site maintenance and also introduces a coefficient c_{bh}, that expresses the backhaul costs, whatever the material of the backhauling is. We describe the annual OPEX C^{ox}_{macro} by the following equation: $C_{macro}^{OX} = N\left(C_{run} + C_{bh}\right)$ (7)

The costs for maintaining the site are linearly proportional to the CAPEX multiplied with a coefficient f_m that denotes costs related to the operation and all the rest site costs, for example the operation, the support etc. are summed by the amount c_{st}. Therefore, the amount Nc_{run} is expressed as: $f_m C^{CX}_{macro} + N c_{st}$. Whereas, the coefficient c_{bh} is not only considered as the backhaul costs, but is linearly proportional to the used bandwidth BW multiplied with a coefficient f_{BW}. Concluding, based on all the assumptions above, the annual OPEX as described in (Liu et al., 2012) is expressed as:

$$C_{macro}^{OX} = f_m C_{macro}^{CX} + Nc_{st} + f_{BW}BW \tag{8}$$

or, by substituting the CAPEX provided by (6), the OPEX is represented by the equation:

$$f_m N(C_{eNB} + C_{EPC})\frac{r(1+r)^{n}}{\left(1+r\right)^{n-1}} + Nc_{st} + f_{BW}BW \tag{9}$$

Reclaiming the (6) and (11) the TCO for macrocellular for the telecommunication operator is represented by the following equation:

$$C_{macro}^{TCO} = (1+f_m)N(C_{eNB} + C_{EPC})\frac{r(1+r)^{n}}{\left(1+r\right)^{n-1}} + Nc_{st} + f_{BW}BW \tag{10}$$

C^{TCO}_{macro} represents the TCO for a macrocellular base station, i is the interest rate and n is the duration of the installment plan expressed in years.

c_{run} represents the main cost paid annually, due to running a single site, including the costs for energy consumption, in-site and off-site support and maintenance and c_{bh} denotes the expenditures for the introduction of the backhauling technology. Thus, the annual OPEX C^{OX}_{macro} is expressed by the following equation: $C_{macro}^{OX} = N(C_{run} + C_{bh})$

We have already shown that all the rest site costs (operation, support, etc.) are expressed by the amount c_{st} and are linearly proportional to the CAPEX, which is multiplied with a coefficient f_m. Therefore, the amount Nc_{run} is further expressed as: $f_m C^{CX}_{macro} + N c_{st}$. Moreover, we indicated that the amount c_{bh} represents the backhaul costs and is considered to be linearly proportional to the used bandwidth BW multiplied with a coefficient f_{BW}. So, the annual OPEX issued in (6), (10) is expressed by the following equation:

$$C_{macro}^{OX} = f_m N(C_{eNB} + C_{EPC}) \frac{r(1+r)^n}{\left(1+r\right)^{n-1}} + Nc_{st} + f_{BW} BW \tag{11}$$

Based on (6) and (11) the TCO for the mobile network operator on an annual basis is expressed by the following equation:

$$C_{macro}^{TCO} = 1 + f_m N(C_{eNB} + C_{EPC}) \frac{r(1+r)^n}{\left(1+r\right)^{n-1}} + Nc_{st} + f_{BW} BW \tag{12}$$

where C^{TCO}_{macro} is the TCO for a macrocellular base station, i is the interest rate and n is the duration of the installment plan expressed in years.

4.4. DAS Deployment

In this subsection, the costs for the DAS deployment is slightly different from the two previous cases. The TCO consists of three main parts: CAPEX, OPEX and IMPEX (Implementation Expenditure).

4.4.1. Capital Expenditure

CAPEX has already been considered and researched in the past and includes the costs for the following assets (Liu et al., 2012):

- The DAS base station,
- The distributed system, such as the remote antennas, the power splitters, the wide-band combiners, coaxial cable or optic fiber cable, cable connector, etc.
- The backhaul equipment whether is optic fiber or coaxial cable and the software cost
- The supporting equipment, such as Wall mounting kit, the power cable, the battery backup, possibly existing alarm system, etc.

The DAS includes a base station that is similar to the macrocellular one, this is why, DAS and macrocellular base stations include the same types of costs. The estimation of the costs is that C_{eNB} represents the cost for one DAS base station, as well as any other costs that stem from the site acquisition or the construction or any backhaul costs for the eNB nodes. C_{EPC} represents the EPC costs and are made for the network's routing. The TCO for the network equipment is expressed by the following equation: $C_{eNB} + C_{EPC}$.

The estimation of the CAPEX for the DAS deployment should be made annually by taking into consideration the annual installment payments of the investment. We pay a total investment plan for CAPEX. If there are N base stations, then the total base station's cost is expressed by the subsequent equation: $N(C_{eNB} + C_{EPC})$. Generally, the annual investment plan for the base station is based on the costs that are described in similar networks, such as the macrocellular base station presented by the C_{EPC} (Bouras et al., 2014).

We consider that the CAPEX for the DAS base station deployment accrues the following budget $N(C_{eNB} + C_{EPC})$ that needs to be overpowered from the beginning, and by using the hypothesis (1) we could calculate the DAS base station costs. The CAPEX estimation on an annual basis for the DAS base station is expressed by the following equation:

$$C_{BS}^{CX} = N\left(C_{eNB} + C_{EPC}\right)\frac{r\left(1+r\right)^{n}}{\left(1+r\right)^{n-1}} \quad (13)$$

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

It is valuable to analyze the necessary expenditures, because of the additional equipment needed in a DAS system for the Distributed System. The coefficient C_{eq} represents the equipment needed for the DAS structures and is linearly proportional to another factor d, that depends on the total number of the DAS structures that exists in the distributed system. Therefore, we describe the CAPEX for the antenna system annually by introducing the subsequent equation:

$$C_{DASEQ}^{CX} = C_{eq} d\,\frac{r\left(1+r\right)^{n}}{\left(1+r\right)^{n-1}} \quad (14)$$

where C^{CX}_{DASEQ}, denotes the annual total CAPEX for the DAS equipment.

The complete DAS CAPEX is the sum of the costs of all the DAS features and is described by the following equation:

$$C_{DAS}^{CX} = (C_{eq} d + N\left(C_{eNB} + C_{EPC}\right))\frac{r\left(1+r\right)^{n}}{\left(1+r\right)^{n-1}} \quad (15)$$

where C^{CX}_{DAS} denotes the annual total CAPEX for the whole DAS system.

4.4.2. Operational Expenditure

DAS OPEX was described as the sum of the above expenditures (Liu et al., 2012):

- Costs of backhaul operations and maintenance. It is possible for some parts of the backhaul to need replacement after a period of time.
- The backhaul rent, if the site is rent,
- The consideration of the power consumption costs, because of the energy consumption.
- The off-site support,
- The site visit for trouble shooting or maintenance,
- The leasing costs, in case the site is leased.

The DAS base station denotes costs, such as c_{run} that represents the annual total cost for running a single site, also computing the energy consumption, in-site and off-site support and maintenance and c_{bh} denotes the backhaul cost. So, the OPEX for the DAS base station is described as follows: $C_{DAS}^{OX} = N\left(C_{run} + C_{bh}\right)$ (16)

Whereas, the coefficient c_{bh} expresses the backhaul costs, which are linearly proportional to the used bandwidth, that is described by the coefficient BW multiplied with a coefficient f_{BW}, that represents the backhaul costs in relation with the available bandwidth. To simplify the produced equations, we consider that the maintenance costs are linearly proportional to the CAPEX multiplied with a coefficient f_{st}, that denotes the operational and the site costs and we represent all the other kinds of expenditures by the amount c_{run} that represents the costs for running a DAS system. Thus, the OPEX for running the DAS base station is further expressed as:

$$NC_{run} = f_{st} C_{DAS}^{CX} \tag{17}$$

where N is the number of DAS nodes, and C^{CX}_{DAS} is the CAPEX of the DAS.

We compute the costs for the maintenance and operation of the distributed system. This includes the maintenance of the antenna structures, because of the antennas and feeders at every floor of the building, but also includes any extra occurring activities. The coefficient C_{eq} denotes the costs that are included for the DAS assets, for example the antennas and the feeders, that are situated in every floor of the building. Subsequently, the annual OPEX for the distributed system is expressed by the following equation:

$$C_{DASEQ}^{OX} = C_{eq} d \frac{r\left(1+r\right)^{n}}{\left(1+r\right)^{n-1}} \tag{18}$$

The DAS system, such as every other network structure needs to consume power, in order to operate. It is therefore, significant, to introduce the energy consumption cost described by the coefficient C_{pw} To summarize, the total OPEX per year for the DAS cells is expressed as follows:

$$C_{DAS}^{OX} = N(C_{run} + C_{bh}) + Nc_{st} + f_{BW} BW + (f_{st} + C_{DAS}^{CX} + C_{pw} + C_{eq} d) \frac{r(1+r)^{n}}{\left(1+r\right)^{n-1}} \tag{19}$$

4.4.3. Implementation Expenditure

IMPEX is the budget that the owner of the system should pay if the cellular site is moved. Consequently, it describes the amount of money that is spent and is associated with planning and installing the network as referred in former research. According to (Liu et al., 2012) it is split in the following costs:

- The costs of the installation of base stations,
- The cost of the installation of distributed system,
- The coordination cost due to disruptive DAS construction work, etc.

The installation expenditures have already been considered according to the C^{CX}_{DAS} analysis, because the main assumption used includes every asset of the distributed system. On the other hand, there emerge coordination costs, because whenever we install some new DAS equipment, it is possible to make adjustments to the existing network in order to succeed the best operation of the total system. The cost of installation and coordination is described by a coefficient C_{inc}. So, the total IMPEX for the DAS is expressed by the following equation:

$$C_{DAS}^{IX} = C_{inc} \tag{20}$$

Finally, the TCO per year for DAS is described as the sum of the CAPEX, OPEX and IMPEX, so it is represented by the following equation:

$$C_{DAS}^{TCO} = N\left(C_{eNB} + C_{EPC} + C_{eq}\,d + f_{st} + C_{DAS}^{CX} + C_{pw} + C_{eq}d\right) \cdot \frac{r(1+r)^{n}}{\left(1+r\right)n-1} N(C_{run} + C_{bh}) + f_{BW}BW + C_{inc} \tag{21}$$

5. PRICING MODELS

In this section, it is crucial to analyze the pricing models, with the parameters and the variables included in the equations in order to calculate all costs and run several experiments in order to deduce fundamental conclusions for the adoption of the most favorable technology. Before conducing any experiments, it is of great value to make a thorough presentation of the parameters of the model. The selection of the parametrization remains a controversial issue. Many of the parameters are not only time dependent, (e.g. some expenditures are augmenting or diminishing when time elapses), but also market dependent, because of the different costs some assets and works may present in alternative economies. Analytically, the installation cost in an African or an Asian economy is definitely cheaper than the ones presented in the European or American markets.

By conducting a detailed research activity, we were finally lead to the parameters' and coefficients' costs in Greece for the year 2016 for the case of an ultra-dense deployment based on femtocells and a corresponding DAS deployment, that are presented in Tables 1 and 2 respectively. In the two tables, not only we present the values found, but also the papers that the occurring expenditures are included. We opted for the following parameters based on the assumptions made for the network market for the next years in European countries. In papers (Bouras et al., 2014; Correia et al., 2010; Markendahl et al., 2010) there are many pricing data when it comes to femtocells and small cells. (Liu, 2013; Liu et al., 2012) present a thorough investigation on DAS costs and parameters.

6. EXPERIMENTAL RESULTS

In this section, we conducted experiments for the deployments' costs. We analyze the most fundamental suggestions that are combined with the corresponding technologies and we end up reaching several vital results. We consider as a fundamental fact to show how the costs fluctuate if there is a need in creating a new base station from scratch. We apply the prices found from the thorough research conducted and we tested our mathematical models. We consider, that the most important cases are the CAPEX, the OPEX and the TCO. In particular, we analytically present the following three technological suggestions:

- Femtocells (FEMTO).
- DAS including the deployment of a brand new macrocell base station (DAS NB).
- DAS without including the deployment of the macrocell base station (DAS W/O NB).

Figure 4 depicted the CAPEX of the upper simple case experiments. It presents the main comparison of the three upper cases for CAPEX. Unlike, what we expected the CAPEX for both DAS deployments are much lower than the ones presented by femtocells. Moreover, the costs of the DAS are stable and the augmentation of the antennas does not affect the investment expenditure. The macrocell base station contributes slightly in the costs, because DAS with deploying a new macrocell base station is not more expensive than the one without considering such a deployment. On the other hand, femtocells' costs are linearly proportional to the number of the antennas added and when the number of antennas is increasing the expenditures are augmenting too.

Table 1. Cost Parameters and System Variables of DAS

Parameter	Description	Value
C_{eNB}	Capital cost for Enb	1000€ (Bouras et al., 2014)
C_{EPC}	Core network's capital cost for the deployment of a single eNB	110€ (Markendahl et al., 2010)
N	The total number of eNB's and EPC's needed	1 (Bouras et al., 2014)
i	Annual interest rate	6% (Bouras et al., 2014)
n	Duration of installment plan of a site in years	10yrs (Bouras et al., 2014)
r	Periodic interest rate	6% (Bouras et al., 2014)
C_{eq}	Cost of DAS equipment	11900€ (Liu, 2013)
d	Factor related to the number of DAS structures	0.002
f_{st}	Linear coefficient correlating site maintenance costs with capital expenditure	0.8 (Johansson et al., 2005)
c_{st}	Site costs apart from maintenance costs with capital expenditure	3100€ (Correia et al., 2010)
C_{run}	Running costs, such as single site, in-site, off-site	892.5€ (Liu et al., 2012)
C_{bh}	Backhaul costs for microwave/optic fiber	3800 € /4800€ (Liu, 2013)
BW	Backhaul bandwidth for a site's interconnection	10Gbps (Bouras et al., 2014)
f_{BW}	Linear coefficient correlating site annual backhaul costs with provided bandwidth expressed in € /Gbps	1170 (Bouras et al., 2014)
C_{pw}	Operational costs for the energy consumption of femtocell OPEX costs	157.68€ (Liu, 2013)
C_{inc}	Implementation costs for the installation and the coordination of the system	2800€ (Liu, 2013)

Table 2. Cost Parameters and System Variables of femtocells

Parameter	Description	Value
C_{eNB}	Capital cost for Enb	1000€ (Bouras et al., 2014)
C_{EPC}	Core network's capital cost for the deployment of a single HeNB	110€ (Markendahl et al., 2010)
N	The total number of HeNB's and EPC's needed	1 (Bouras et al., 2014)
i	Annual interest rate	6% (Bouras et al., 2014)
n	Duration of installment plan of a site in years	10yrs (Bouras et al., 2014)
r	Periodic interest rate	6% (Bouras et al., 2014)
f_m	Linear coefficient correlating site maintenance costs with capital expenditure	0.8 (Johansson et al., 2005)

The operational expenditures for previous cases are presented in Figure 5. The exact opposite fact from the one presented in the case of CAPEX is happening for this analysis. All the expenditures are stable, when the number of antennas augments, but in this case, femtocells present lower costs. On the other hand, DAS' operational expenditures are very high and as a matter of fact contribute a lot to its TCO. Also, in the DAS cases the deployment of the macrocell base station contributes to some more expenses and assists to the fact that it is the higher of all the presented costs. DAS TCO

Figure 4. The comparison of the CAPEX for DAS and Femtocells

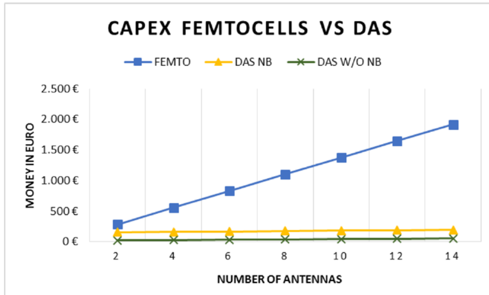
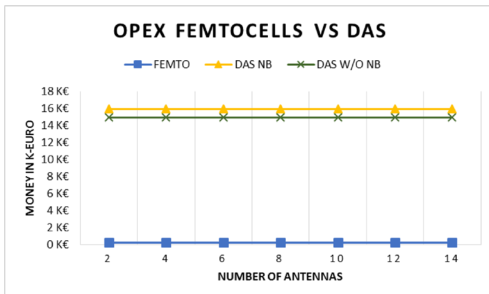


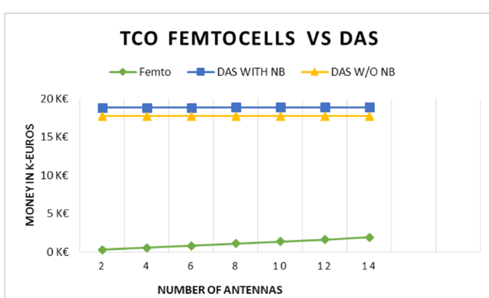
Figure 5. The comparison of the OPEX for DAS and Femtocells



is very expensive, because of its high OPEX and it is stable, while femtocells' TCO is smaller, but augments linearly proportional to the antennas' augmentation (Figure 6).

In addition, examining the TCO Figure 7 for different backhaul technologies, when the number of antennas augments, the TCOs of both DAS deployments are higher, but are fixed amounts. The DAS deployments with a macrocellular base station are higher, than the others without implementing the base station. The backhaul technology does not affect much the costs, although the higher cost is noted for the DAS case with forming a macro base station and using fiber as backhaul technology. So, it enables network operators to add optic fibers. Femtocells' expenditures augment linearly, while the number of antennas is increasing. In the respective case of CAPEX presented in Figure 8, the DAS without a base station deployment for microwave or fiber is lower to the other ones. DAS CAPEX is low, while femtocells' is linearly augmenting while adding several antennas.

Figure 6. The comparison of the TCO for DAS and femtocells



It is crucial to point out the need of studying the case of a very large infrastructure. Supposing several decades or a hundred of antennas needed Figure 9, we conclude that the DAS' TCO expenditures are stable and high. The DAS with deploying a macrocellular station are once again higher than the others without the deployment of the macrocell base station. On the other hand, the femtocells' costs are linearly proportional to the number of antennas added in the system. For one hundred antennas, the femtocells' expenditures equal the DAS costs. The same experimental procedure for the CAPEX is depicted in Figure 10, while increasing the number of antennas the femtocells' CAPEX is the highest one as it is linearly proportional to the number of antennas added. For both cases of DAS, the CAPEX are extremely lower and stable compared to the femtocells' and the one with the deployment of a base station remains higher than the one without implementing it.

Figure 7. The comparison of the TCO for DAS and femtocells for different backhaul solutions

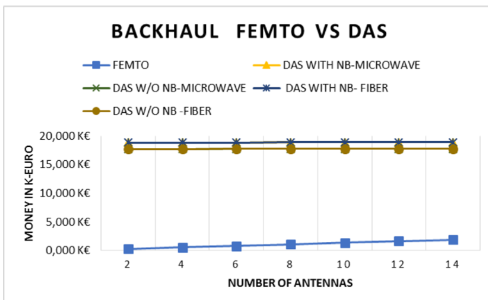


Figure 8. The comparison of the CAPEX for DAS and femtocells for different backhaul solutions

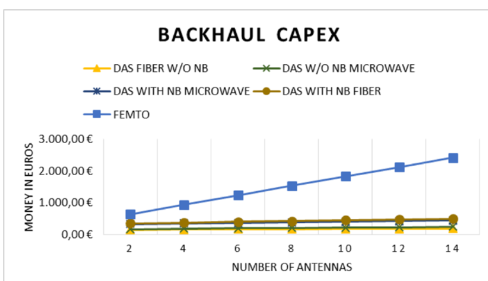


Figure 9. The comparison of the DAS and femtocells for very large buildings

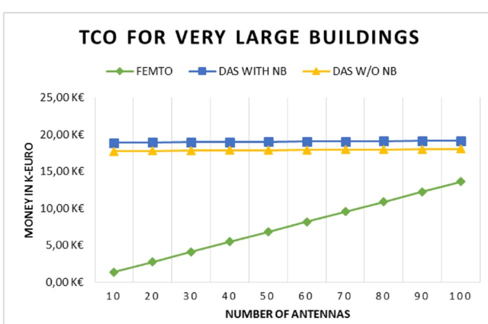
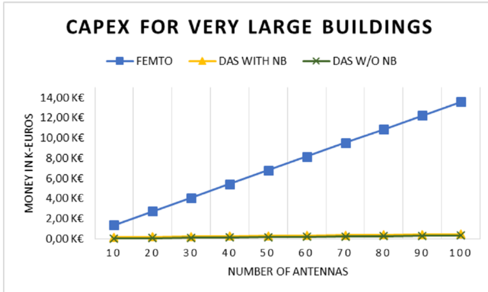


Figure 10. The comparison of the CAPEX for DAS and femtocells for very large buildings



We depict the TCO in Figure 11 considering the installment plan over the years. The TCO is extremely high, in both DAS deployments while the femtocells' costs seem to decrease, while years elapse. For example, from two to four years the expenditures are higher than they are in the next years. From six to twenty years the expenses stabilize. The DAS' costs are higher compared to the femtocells'. The CAPEX for all deployments follow a parabolic orbit. Analytically, the two cases of DAS and the one of femtocells decrease while time elapses, but femtocells' CAPEX is higher than those of the DAS'. The CAPEX costs are depicted in Figure 12. CAPEX is decreasing with the elapsing of years for all cases. The fluctuation is larger for the femtocell case and smaller for the DAS cases.

From the previous experiments we conclude that DAS is slightly different compared to femtocells, a fact also depicted in their costs. DAS contributes to an operator much OPEX and as a result, it is

Figure 11. The comparison of the TCO for the investment plan for DAS and femtocells over the years

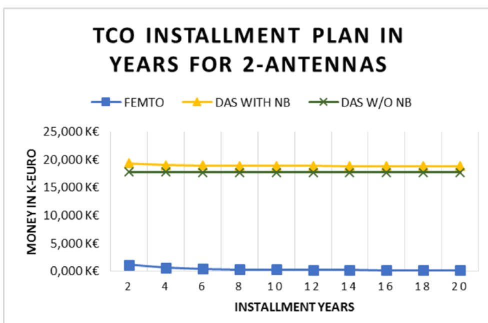
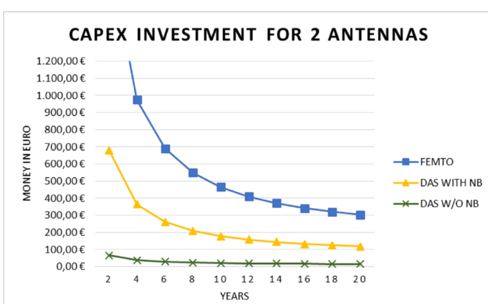


Figure 12. The comparison of the CAPEX for the investment plan for DAS and Femtocell over the years



fundamental to reduce OPEX via diminishing power consumption and intelligent network management practices. On the other hand, femtocell's CAPEX is larger, but mostly burdens a subscriber that opts for obtaining it. According to the application, one could opt for the more convenient deployment. DAS covers a larger area, but costs more and femtocells cover a couple of users.

Finally, we point out that the experimental procedures and the results describe the situation of the Greek market in 2016 and therefore, Tables 1 and 2 present the parameters and coefficients, that appear in the Greek market. It is possible to parameterize the problem with different cost values for other markets for future experimental cases. The parameters are obtained via thorough literature activity in the field of telecommunications. This study is different from other similar ones, because it gathers many cases of femtocells and DAS. It contributes elaborating on the subject and concludes about all the important matters raised before.

7. CONCLUSION

In this paper, we presented several experiments for the cost calculation of femtocells and DAS. TCO for femtocells is lower than the costs of DAS for most cases. We examined TCO, CAPEX and OPEX for the two suggestions, experimenting with the number of antennas in accordance with the backhauling technology, the years of investment for the deployment of technologies and the very large buildings that include many antennas.

In most cases, femtocells cost less than DAS. For very large places, femtocells are not a favorable solution, because the exponentially augment their TCO and finally, cost more than DAS. On the other hand, DAS is cost effective when it covers a large area without a high augmentation of costs. For little areas, the coverage provided by femtocells is helpful and the costs they induce are low and affordable by a single subscriber. DAS imparts larger OPEX, so it would be vital techniques to be developed to decrease these types of costs. Femtocells induce low OPEX, because even a not expert user is able to fix some problems raised and placement and maintenance costs are the minimum possible. CAPEX is larger for femtocells, but a user quickly depreciates his investment when uses them, especially reclaiming possibilities, they offer such as accessibility to other users.

8. FUTURE WORK

In the future, a large amount of scientists will be interested in the mobile network's cost calculation and will use our study, in order to conduct several experiments and induce a wide range of important conclusions in the expenditure cases. This study presents a flexibility, that is related to the fact that it mathematically describes the model, so it is easy for a scientist to apply new prices in the future or prices of a different market, not necessarily European or Greek. In the next years, we suggest that scientists should deal with other significant issues as well, such as the expenditures related to the bandwidth, the depreciation for each technology, the power consumption, the technology's life-cycle, the usage, the base station costs or even the density of the deployments, improving the suggested model and diminishing the OPEX costs of DAS.

Scientists would deal with a huge variety of selections for femtocells, such as user group selection, femtocell safety, reduction of power consumption, reduction of base station costs. Marketing and management forwarding convincing users about the benefits of femtocells should also be considered. There is also a need in delineating the future of femtocells combined with other different technological suggestions, such as Software Defined Networking in Wireless Networks and the way of their management by the SDN software. DAS should be investigated in order to diminish its basic costs for both the indoor and outdoor cases and alternatives to reduce their high OPEX should be proposed. There should also be an investigation for health concerns alongside with imposing exact legislation considering these technologies.

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Christos Bouras is Professor in the University of Patras, Department of Computer Engineering and Informatics. Also he is a scientific advisor of Research Unit 6 in Computer Technology Institute and Press - Diophantus, Patras, Greece. His research interests include Analysis of Performance of Networking and Computer Systems, Computer Networks and Protocols, Mobile and Wireless Communications, Telematics and New Services, QoS and Pricing for Networks and Services, e-learning, Networked Virtual Environments and WWW Issues. He has extended professional experience in Design and Analysis of Networks, Protocols, Telematics and New Services. He has published more than 400 papers in various well-known refereed books, conferences and journals. He is a co-author of 9 books in Greek and editor of 1 in English. He has been member of editorial board for international journals and PC member and referee in various international journals and conferences. He has participated in R&D projects.

Vasileios Kokkinos obtained his diploma from the Physics Department of the University of Patras on October 2003. Next, he was accepted in the postgraduate program "Electronics and Information Processing" in the same department and on March 2006 he obtained his Master Degree. In 2010 he received his PhD on Power Control in Mobile Telecommunication Networks from the Computer Engineering and Informatics Department. He works in the Research Unit 6 of Computer Technology Institute and Press "Diophantus" since September 2006. His research interests include data networks, third and fourth generation mobile telecommunications networks, multicast routing and group management and radio resource management. He has published several research papers in various well-known refereed conferences and articles in scientific journals.

Anastasia Kollia obtained the Proficiency in English of Michigan University in 2007. She obtained the "Diplome Approfondi de la langue francaise C2" de l' "Institut francais" in 2007. She entered the Computer Engineering and Informatics Department in 2010 and obtained her diploma in 2015. She joined the ru6 of the Computer Engineering and Informatics Department at the University of Patras in 2014 and she has been a member ever since. She is currently a master student in the same department in the Computer Science and Technology. She is a member of the IEEE student branch at Patras since 2015. Her research interests include future mobile and wireless networks, Ultra-dense deployments and Software Defined Networking.

Andreas Papazois is a post-doctoral researcher at Computer Engineering and Informatics Department, University of Patras and an R&D engineer at GRNET S.A. In the past, he worked as telecommunications engineer in Intracom Telecom S.A. His research interests include future mobile networks, ultra-dense deployments and software defined networking. He has published several research papers in various well-known refereed conferences, books and journals. He has been technical committee member for several conferences and a reviewer for various scientific journals.