Chapter 17

Planning of FiWi Networks to Support Communications Infrastructure of SG and SC

Arturo G. Peralta

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.71781

Abstract

Nowadays, growth in demand for bandwidth, due to new and future applications being implemented, for services provided from smart grids (SG), smart cities (SC) and internet of things (IoT), it has drawn attention of scientific community, on issues related to planning, and optimization of communication infrastructure resources, in addition is necessary comply with requirements such as scalability, coverage, security, flexibility, availability, delay and security. Another important point is how to find and analyze possible solutions that seek to minimize the costs involved by capital expenditure (CAPEX) and operational expenditure (OPEX), but where it is possible to measure the uncertainty coming from stochastic projections, in order to obtain the maximum benefit expected to give access to users Who benefits from the services provided by SG, SC and IoT, on the other hand, we must look for communications architectures that generate optimum topologies to meet demanded requirements and at the same time save energy, possible alternatives highlight the use of hybrid networks of optical fiber links combined with wireless links (Fiber-Wireless, FiWi). This chapter seeks to provide planning alternatives to network segments linking universal data aggregation point (UDAP) with base stations (BS), this segment joins wide area network (WAN) with metropolitan area network (MAN).

Keywords: FiWi networks, internet of things, planning, scalability, smart cities, smart grids, stochastic programming

1. Introduction

The following chapter proposes a ***new planning model*** for the ***scalability and deployment*** of communications infrastructure that give supports to SG, SC and IoT; countries such as the United States and those that made up the European Union, are carrying out projects with SG motivated by the drawbacks related to the current energy network, such as blackouts, overloads and voltage drops, most of these events were due to a slowness in response times of the devices that control the energy network, in addition, the increase in the population of residential and commercial clients that demand to connect intelligent appliances or the IOT, has caused that the network of supply is obsolete, considering this background, it is urgent to make changes in the infrastructure of electrical and communications systems, so as to adapt to the temporal-spatial evolution of customers and to meet requirements such as: ***scalability, coverage, security, flexibility, availability, delays and latencies*** [1–3].

In order to observe a horizon of temporal-spatial evolution, it is necessary to characterize important parameters such as ***the demand and density*** of users, Who benefit from the services offered by SG, SC and IoT. It is difficult to make accurate forecasts regarding the projection and growth of intelligent electronic devices (IED) given that uncertainty exists because of the number of variables involved, however it is possible to make future projections in a stochastic way, which can serve as a reference for the take of decisions related to the deployment of the communications network, which supports the services provided on SG, SC and IoT, but testing various planning scenarios.

Another point to highlight is how to find and analyze possible solutions that seek to minimize the costs involved by CAPEX and OPEX to maximize the benefits expected by telecommunications operators. Therefore, communication architectures that generate optimal topologies should be sought, in order to meet the requirements demanded by SG, SC and IoT and that at the same time save energy; possible alternatives from the scientific community point to the use of FiWi Hybrid Networks [4–9].

The systems implemented through SG and SC are characterized by important parameters such as user density, types of services provided, spatial and geographical location of resources like communications infrastructure [1, 10–15], which is the backbone of SG, SC and IoT. On which applications and services such as automated meters reader (AMR), or with more extended services advanced metering infrastructure (AMI), which for example help in detecting system failures such as: communications, failures in devices like sensors, actuators and/or controllers or failures due to control system and resources scheduling [16].

As for electricity distribution in terms of a smart grid, the terminology of distributed generation (DG) or distributed energy resources (DER) is introduced. In this way, the der goes from having few generation centers to having a large number distributed generation centers throughout electrical network, which can be renewable and/or traditional, forming interconnected micro-networks [17]. The main advantage of having DER is that distribution network operators (DNOs) can quickly and efficiently reconfigure and redirect power flow in response to events such as failures, changes in demand or even changes in energy generation costs.

Furthermore, storage sources include traditional high-performance batteries such as lead-acid, sodium sulfide, lithium ions, and others, but studies are being made of materials and alloys that will form batteries of greater capacity, durability and more economical that the current ones. In ([18], chapter 1) are mentioned membranes and cells that are in process of investigation like polymer electrolyte membrane (PEM) and hydrogen fuel cells (HFC).

On the other hand, in the next years a considerable increase in the penetration of electric vehicles (EV) is expected and the most common will be plug-in electric vehicles (PEV) and plug-in hybrid electric vehicles (PHEV), in [19–21] the requirements are mentioned that must satisfy a SG to meet these challenges.

All these services and applications required by users of SG, SC and IoT, grow over time, like a tree that expands its leaves, in this way services implementation layers provided by SG and SC will be created them across different stages temporal, in addition to all this, the information flow must be conducted in a secure and scalable manner, on the different network segments how are: personal area network (PAN) and Home area network (HAN) see **Figure 1**, Neighborhood area network (NAN), WAN, and MAN see **Figure 2**.

1.1. Scalability of FiWi networks

Figure 2 shows different users who are geographically located in four subregions that form a planning area, these future clients will benefit from the services provided by SG, SC and IoT, such as smart metering (energy, gas, water) demand response, power storage, civil security, community alarms, smart public lighting, smart road signposting, etc.

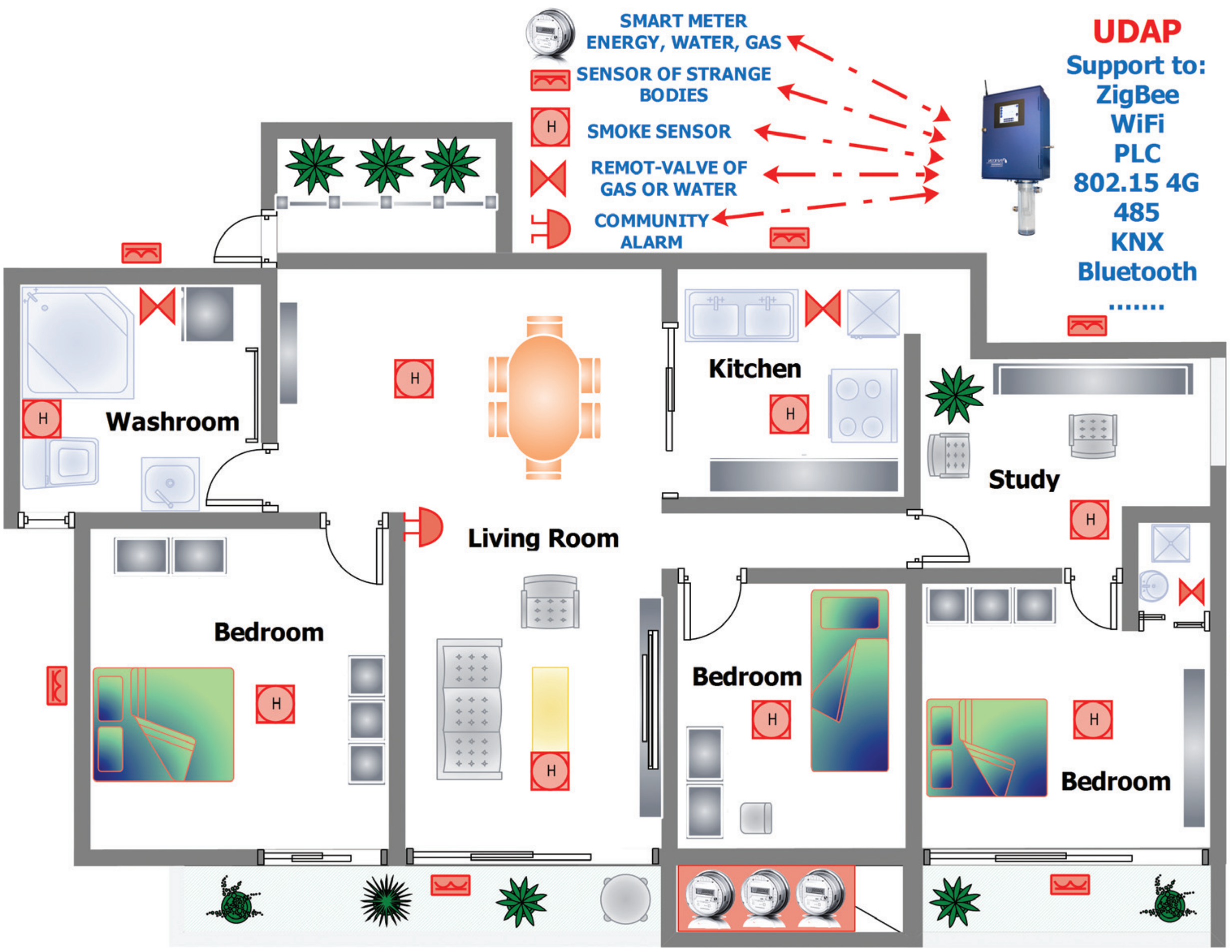

Figure 1. PAN and HAN networks for SG, SC and IoT.

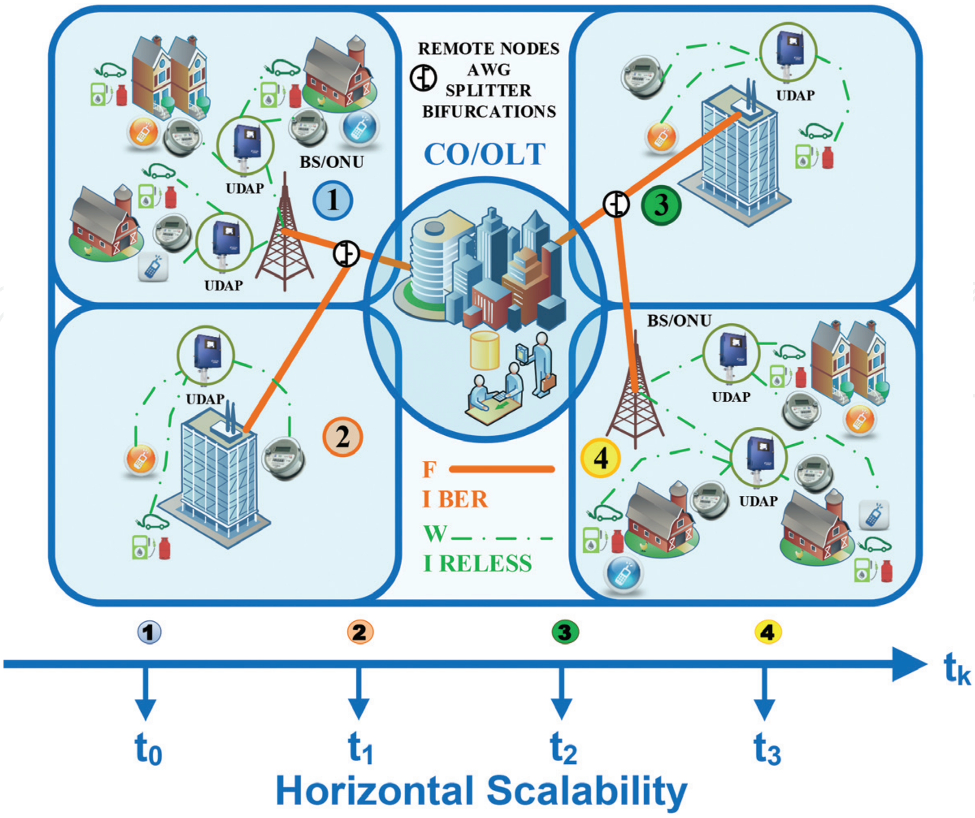

Figure 2. Infrastructure for SG and SC across a horizontally scalable FiWi network in four temporary stages.

To be able to offer these services it is necessary to have an adequate communications infrastructure throughout the region, to manage the flow of information together with the flow of energy. Therefore, **Figure 2** shows how the deployment of a FiWi network to cover and scale horizontally in a timeline to all subregions would be. The configuration of the architecture would be conformed to the wireless access through data concentrators that we have called UDAP. These devices have the ability to carry information from wireless heterogeneous network (WHN) [22], coming from the different wireless sensors network (WSN) to the base stations that function as enhanced node base station (eNodeB), which have a gateway that connects to the optical network unit (ONU) to send the information over a PON that makes fronthaul/backhaul [23, 24] (very high speed) using fiber-optic links in tree topology to optical line termination (OLT), where the co of the public or private service provider is. In the PON network, it is possible to place bifurcations that function as remote nodes (RN) where passive optical equipment such as Splitter (SP) or arrayed waveguide grating (AWG) can be located.

The proposed model seeks to guarantee a horizontal scalability in each stage of time t_k, since by passing a time t_k to t_{k+1}, **Fi**ber Optic and **Wi**reless resources are designated to the FiWi network, by means of actions and policies that add hardware in an optimal way, trying to give the greatest possible coverage to the users that evolve and grow spatially in a timeline and at the same time, returning the maximum economic benefit to investors represented by public or private companies.

This chapter is organized as follows: Section 2 we present the state of the art and related works; in Section 3 problem formulation with the planning model, and the algorithm MOA-FiWi; in Section 4 result analysis. Finally, in Section 5, we present the conclusions and future works.

2. State of art and related works

Aggregation points (AP) over the NAN play a very important role for the communications network that holds SG, so an adequate AP planning model that links to the HAN, can minimize costs in the deployment of SG and it is proposed in Ref. [25]. In addition to this premise, algorithms based on Greedy and clustering techniques are presented; these proposals presented analysis in power line communication (PLC) and optical fiber.

SG proposes a new concept in which electrical energy is generated, transported, distributed and consumed, thanks to the integration between telecommunications and advanced sensors to provide daily control and monitoring of the operation of the energy network within a WAN. Electricity is the key nucleus for the functioning of society and for the provision of services provided by technologies of information and communication (TIC). The works presented in Ref. [26] investigate the challenges and opportunities that can be achieved through the interaction of SG with green TIC, through efficient use of energy with wireless technologies and wired technologies such as PLC and fiber optics, present in the different domains that SG handles such as HAN, NAN and WAN.

On the other hand, the problem of efficient collection of measured data from AMI by reusing existing communications infrastructures such as the cellular network, but facilitated by a primary or secondary operator, the latter through a mobile virtual network operator (MVNO) or cognitive-virtual network operator presented in Ref. [27], requires to analyze the coverage problem in rural areas and the capacity of channels in urban areas due to the density of cellular telephone users. In other words, there is a need to allocate channels in an equitable way to reduce the costs in the lease of the spectrum of frequency.

Significant contributions have focused on the electric energy reserves, which can be managed by sending the information of the data measured by leased secondary channels at the lowest possible price. In order to reduce both costs of energy and communications, a problem called cost minimization for meter data collection (CMM) is formulated. This problem seeks to find an optimal solution for the minimization in the costs involved in the selection of communication channels and a scheme in the programming for the delivery of energy [28].

Within the AMI concept, the sub-steps that constitute the network topology for infrastructure planning must be determined. Thus, we have NAN [29, 30] delimited from the client meter to the UDAP concentrator with an uplink link [31], For this, conglomerates or clusters of smart meters (SM) are created to form NAN where cellular technology such as general packet radio service (GPRS)/long term evolution (LTE) [32] or WiFi and IEEE 802.15.4 g can be used through multiscales [33]. In this way the first stage is completed. Subsequently the different UDAP of NAN form a MAN, which forms the WAN [7, 34], but among NAN and MAN/WAN two solutions can be proposed for boundary zones; thus, we can continue to maintain a wireless cellular solution, WiFi or IEEE 802.15.4 g [35]. According to the coverage and the capacity of each UDAP that will be the one that finally allows the connectivity with the nearest cellular base station, but when the information demand grows substantially a fiber optic return is proposed [36–40], in addition to the interconnection of cellular base stations normally arranged for telephony, thus forming a hybrid network FiWi.

On the other hand, resources allocation is important for network operator profitability, therefore communications network must be dimensioned to satisfy customers' coverage and demand. Considering that these evolve over time, infrastructure must evolve accordingly. The demand growing is difficult to predict, in consequence it constitutes an important uncertainty source.

Strategic planning of communications network must take account this uncertainty, and network evolution must be able to adaptable to market conditions, therefore, the application of advanced planning methods taking into account the uncertainty can improve network profitability and create a competitive advantage. Wireless network planning demands complex tasks and automated procedures that must adapt and support large data demands that flow from current and future technologies, such as LTE, 4G and in a few years 5G.

There are very few contributions from the scientific community, regarding a planning framework that is suitable for various technologies and that demonstrates practical applicability by performing computational experiments using realistic and wide-ranging planning scenarios, where moreover network evolution start from an initial year and scale toward future years.

A popular method for evaluating investment opportunities in several domains with real options is presented in Ref. [41]. The real options approach treats investment projects as options of the outcome of future cash flows and uses the financial market for a neutral monetary valuation in the presence of risk when there are investment opportunities. The real options have been used as a tool in several applications, including telecommunications [42, 43]. In order to correctly apply the theory of real options, the project has to be embedded in an appropriate market.

Furthermore, stochastic programming can be useful as a tool to evaluate real options in the absence of a market embedding [44]. A discount rate must adjust the risk and be used to arrive to an outcome that is an implicit evaluation of paths that form scenarios over a stochastic decision tree.

Since communications network evolution can be divided into several stages, the multistage stochastic programming (MSP) [45] is an appropriate framework for modeling strategic planning on telecommunication networks. Wireless networks planning for cellular telephony through multistage stochastic programming is modeled in Ref. [46], it is left for future works to get a deeper analysis to be able to do FTTx networks planning.

Considering the aspects reviewed in the State of the Art, we can state that important work has been done on the analysis to save energy and provide greater capacity through the use of FiWi in multiservice networks that support SG, SC, and IoT. However, it is a priority to model mathematically in the presence of uncertainty how to deploy a FiWi network in a scalable way to propose a green field planning tool, or to perform access network upgrades or generate backup networks in case of failures. In addition, it is important to optimize the allocation of wireless and wired resources involved to meet the requirements of scalability, coverage and capacity, which is the main contribution and reason for the work we propose.

In this chapter we present a novel model of scalability of FiWi networks, on *Delaunay Triangulation Spaces*; which to our best understanding, it is the first time the combination of scalability

http://dx.doi.org/10.5772/intechopen.71781

analysis is considered (CAPEX and OPEX) introducing uncertainty in the different time-space stages, by multi-stage stochastic programming. The model presents flexibility in decision making as the time stages progress, and this situation allows the planning of green fields, as well as the updating of networks that already have communication infrastructure.

3. Problem formulation

The investigation problem seeks to make a resource allocation, over a temporal-spatial evolution, for communications infrastructure deployment, which will support provided services by SG, SC, and IoT, fulfilling with requirements of scalability and coverage, through use of wired and wireless mediums.

3.1. Planning model

The model proposed in **Figure 3** is divided into four phases which are described below:

3.1.1. Determination of parameters to be projected

- Characterize demand, population or density of users. In order to do this, it is important to have previous statistical data, which can be obtained by surveys, fieldwork or by comparison with previous projects.
- Then, a large number of projection scenarios are constructed at each stage of time. In order to fulfill this step, we can use Wiener stochastic processes (WSP), also known as geometric Brownian motion (GBM), whose model is represented in (1). This process is characterized by two parameters such as the expected growth rate μ and the volatility σ that generates uncertainty values at each time stage of a projection path. More features, properties and details of this stochastic process can be found in [47, 48].

$$\frac{d\mathbb{S}_t}{\mathbb{S}_t} = \mathrm{m}\ \ dt + \mathrm{s}\ \ d\mathbb{F}_t \tag{1}$$

- The evolution steps that generate a large number of scenarios are reduced by the techniques proposed in Ref. [49]. As a result a multistage stochastic projection tree (MSPT) is obtained.

3.1.2. Region of planning and location of candidate sites

With the data generated by the MSPT, the candidate sites for base stations, fiber-optic links, location of the central office and potential users will be located. These sites will evolve over a time line for each of the routes in the MSPT scenarios.

It is important to note that the coverage radios can be combined for macro, micro and femto cells. In this way, ***horizontal scalability*** (coverage requirements) and ***vertical scalability*** (increase capacity) can be given as users grow spatially in the planning region.

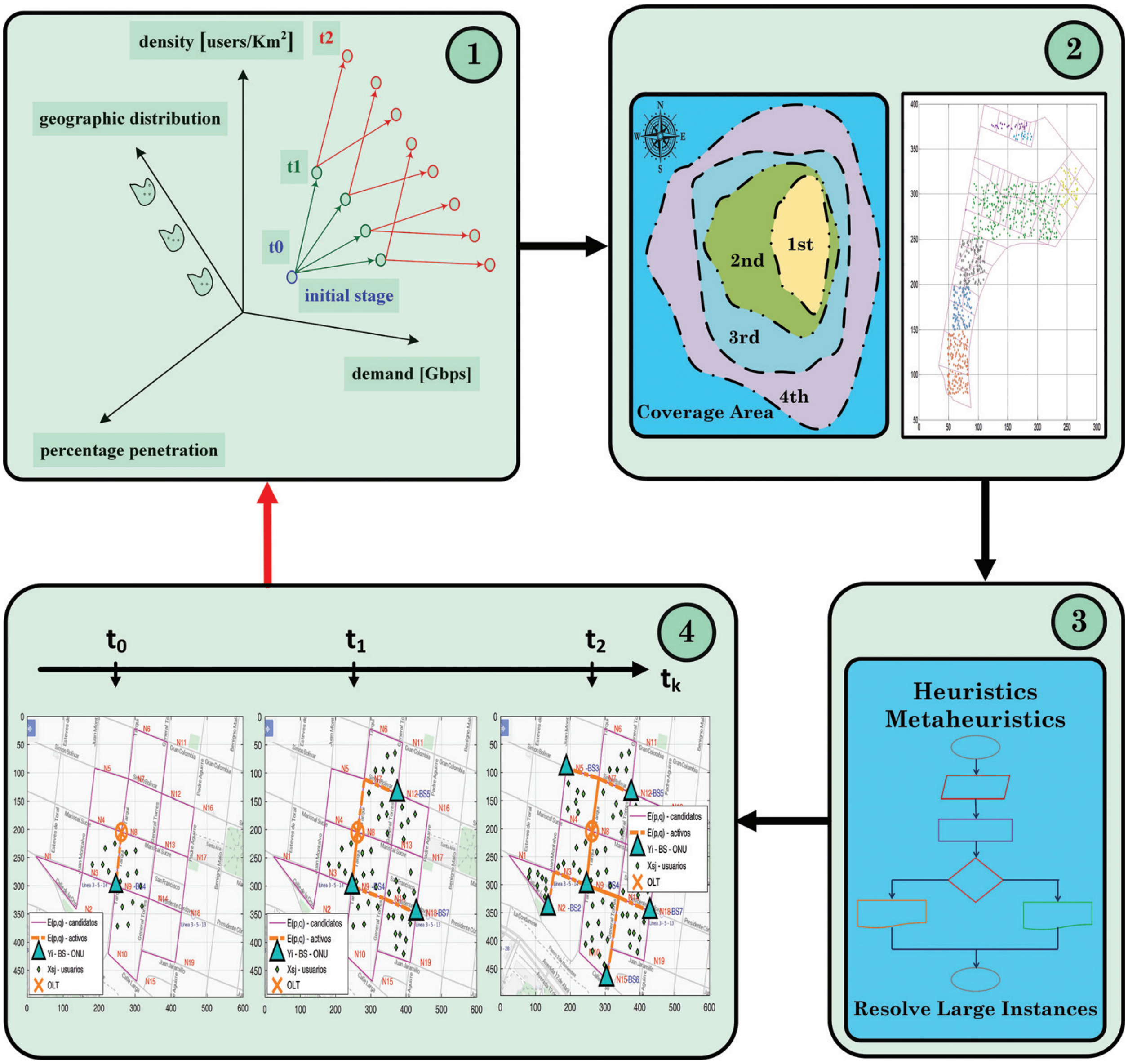

Figure 3. FiWi planning model.

Horizontal scalability, refers to the growth of the FiWi network over time, and in conformity with the evolution and growth of users. Therefore, this type of scalability does not observe the behavior of the process in a single instant of time (as a single photo or image of the scalability process). On the contrary, it is a process that changes, evolves and adapts automatically over time, according to the addition of hardware (base stations, fiber-optic links, etc.), from a time t_k to t_{k+1}.

On the other hand, with the ***horizontal scalability*** capacity is not guaranteed, it can even be very limited. Then, to address the issue of capacity, the issue of ***vertical scalability*** is stated, whose objective is to increase capacity without increasing the deployment of the communications infrastructure.

For ***vertical scalability***, it is important to clarify that it is not part of the scope of this work to perform exhaustive analysis of capacity, interference and topology performance that can result as a possible solution.

Carrier aggregation	**Intra-carriers**
	Inter-carriers
Spatial multiplexing using techniques	MIMO
	MISO
	SIMO
	SISO
Relay nodes	Microcells
	Femtocells
Fronthaul/Backhaul	NG-PON1
	NG-PON2
	DWDM
	UDWDM

Table 1. Alternatives of vertical scalability.

However, in general, there are alternatives for technological updating, which increase the capacity for each user, which is added to the future in a time $\boldsymbol{t_{k+1}}$.

Moreover, the optimization model proposed by mixed integer linear program (MILP) is very versatile to adapt it to any wireless and fiber-optic technology; for example, chosen as wireless resources to work under LTE-Advanced-4G, and for the wired fiber optic network xPON, the alternatives for technological updating would be those presented in **Table 1**.

3.1.3. Description of the MILP optimization model

There is a planning area $\mathbb{A}$ made up of users coming from services provided by SG and SC conglomerated through UDAP, situations which next will be represented by the binary variable $X_{s_j}^n$ whose value is one if one j^{th} UDAP is served and covered within a time stage $\boldsymbol{t}_k$ for a node n of MSPT, or zero otherwise; the information of $X_{s_j}^n$ is conveyed toward the base stations forming a $\mathbb{C}$ set of candidate cells for coverage, as long as restrictions are met at the energy thresholds that hold connectivity in wireless links, then, when a i^{th} base station is activated in a stage of $\mathrm{t_k}$ for a node n of MSPT, the variable Y_i^n becomes one or zero; on the other hand, any candidate cell in a parent node $p(n)$ of MSPT remains active when scaling horizontally from time $\boldsymbol{t}_k$ to time $\boldsymbol{t}_{k+1}$. It is possible to carry out the technological upgrades indicated in **Table 1**.

All the active base stations incorporate a Gateway that allows to migrate the information at high speed by ONU through fiber-optic links that are selected from a graph $\mathbb{G}(\mathbb{V}, \mathbb{E})$, configured by a grid of streets, Avenues and intersections that lie within $\mathbb{A}$. Consequently, if a link is activated in a time stage $\boldsymbol{t}_k$ for a node n of MSPT, the variable $Z_{p,q}^n$ becomes one or zero otherwise.

The active links form a PON network in tree topology, whose two-way information flows, go from the ONUs to the Central Office where they have OLT. It is not the object of this work to perform an analysis of intermediate passive equipment, such as optical splitters SP and optical routers AWG. This is justified because the major cost in an investment is in the construction of the PON network; that is to say, it is directly related to the laying of fiber-optic cable which also requires civil works such as conduits, pipelines and fittings to guide the laying of the transmission medium. However, if the positioning of bifurcations which act as RN is allowed, after the optimization process and depending on the configuration of the PON network, SP or AWG will be located. These equipment would be part of the technological upgrades indicated in **Table 1**.

Similar to what happens with active base stations, if a $Z^{n}_{p,q}$ link of optical fiber is chosen in a parent node $p(n)$ of MSPT, it remains active when scaling horizontally from time $\boldsymbol{t}_k$ to time $\boldsymbol{t}_{k+1}$, it is allowed to make branches to add RN, and make fronthaul/backhaul to the new cells that are going to be activated in the future. In this way, the reuse of guided transmission media such as the optical fiber is optimized.

Then, the proposed MILP model seeks to maximize the benefit expected by the investment in the deployment of the FiWi topology, $D^* : argmax\mathbb{E}\{\mathbb{R}\}$, there are two ways to solve it. The first is through the use of mathematical optimization software, which could only treat small instances of the problem, since if the proposed MILP model is simplified and relaxed in some restrictions, then we have the equivalent of a maximum coverage problem (MCP); in this way, it can be stated that the complexity present in the proposed optimization problem is ***NP-Hard*** type.

The second way to deal with the solution is to approximate feasible solutions by means of the heuristics and metaheuristics approach to provide ***computational scalability*** through polynomial models that do not grow exponentially to the size of the system; with this we could treat medium and large instances of the problem. The detailed formulation of the multistage stochastic optimization problem and the algorithms proposed on the basis of policies are discussed in the following subsections.

3.1.4. Appropriate horizontal scalability path

The last phase of the scalable planning model for FiWi networks to get the information optimized by the MILP model, is to perform an adequate analysis to make decisions.

In the last stage of time there are some scenarios, formed by paths that run through the MSPT, where each node n contains the topology FiWi and the UDAPs to be covered.

The scenarios can be classified as ***conservative, realistic and optimistic,*** depending on the degree of uncertainty they have. The tools, such as the analysis of real options [44, 50], can help to select which ***horizontal scalability paths*** are suitable within the MSPT.

On the other hand, the model is dynamic and if necessary future scenarios can be reformulated at any stage of time, and the planning model process is the same as described in Section 3.1.1–3.1.4 presented in **Figure 3**.

3.2. Objective function

The $D^* : argmax\mathbb{E}\{\mathbb{R}\}$ is detailed in (2–12), It is important to indicate that all values are carried at net present value (NPV); CAPEX is loaded at the beginning of a year; income and OPEX at the

http://dx.doi.org/10.5772/intechopen.71781

end of a year and since there is no OPEX value for year zero, investment at both the beginning and the end of this year is high, giving negative cash flows in some cases:

$$argmax\mathbb{E}\{\mathbb{R}\} = \mathbb{R}^{UDAP}_{profit} - \mathbb{C}^{BS}_{capex} - \mathbb{C}^{OF}_{capex} - \mathbb{C}^{BS}_{opex} - \mathbb{C}^{OF}_{opex} \tag{2}$$

Subject To:

$$\mathbb{R}^{UDAP}_{profit} = \sum_{n\varepsilon\mathbb{N}} \mathbb{P}(n) \sum_{j\varepsilon\mathbb{A}} \widehat{\mathbb{I}}^{n}_{j} \; X_{s_j}^{n} \tag{3}$$

$$\widehat{\mathbb{I}}^{n}_{j} = \frac{\mathbb{I}^{n}_{j}}{(1+r)^{t_k}} \tag{4}$$

$$\mathbb{C}^{BS}_{capex} = \sum_{n\varepsilon\mathbb{N}} \mathbb{P}(n) \sum_{i\varepsilon\mathbb{C}} \widehat{\mathbb{C}}^{capex,\,n}_{i} \left(Y^{n}_{i} - Y^{p(n)}_{i}\right) \tag{5}$$

$$\widehat{\mathbb{C}}^{capex,\,n}_{i} = \frac{\mathbb{C}^{capex,\,n}_{i}}{(1+r)^{t_k-1}} \tag{6}$$

$$\mathbb{C}^{BS}_{opex} = \sum_{n\varepsilon\mathbb{N}} \mathbb{P}(n) \sum_{i\varepsilon\mathbb{C}} \widehat{\mathbb{C}}^{opex,\,n}_{i} \; Y^{n}_{i} \tag{7}$$

$$\widehat{\mathbb{C}}^{opex,\,n}_{i} = \frac{\mathbb{C}^{opex,\,n}_{i}}{(1+r)^{t_k}} \tag{8}$$

$$\mathbb{C}^{OF}_{capex} = \sum_{n\varepsilon\mathbb{N}} \mathbb{P}(n) \sum_{p,\,q\varepsilon\mathbb{E}} \widehat{\mathbb{C}}^{capex,\,n}_{p,q} \; \widehat{\mathbb{D}}^{n}_{p,q} \left(Z^{n}_{p,q} - Z^{p(n)}_{p,q}\right) \tag{9}$$

$$\widehat{\mathbb{C}}^{capex,\,n}_{p,q} = \frac{\mathbb{C}^{capex,\,n}_{p,q}}{(1+r)^{t_k-1}} \tag{10}$$

$$\mathbb{C}^{OF}_{opex} = \sum_{n\varepsilon\mathbb{N}} \mathbb{P}(n) \sum_{p,\,q\varepsilon\mathbb{E}} \widehat{\mathbb{C}}^{opex,\,n}_{p,q} \; \widehat{\mathbb{D}}^{n}_{p,q} \; Z^{n}_{p,q} \tag{11}$$

$$\widehat{\mathbb{C}}^{opex,\,n}_{p,q} = \frac{\mathbb{C}^{opex,\,n}_{p,q}}{(1+r)^{t_k}} \tag{12}$$

3.3. Wireless coverage restrictions

The constraints in (13–16) control the *horizontal scalability* provided by the maximum wireless coverage. The restriction (13) ensures that each UDAP has service and coverage, restriction (14) prevents base stations from being destroyed from parent nodes to child nodes in the MSPT. It should be noted that the parent root node in MSPT is reflected by the variable $Y_i^{p(r)} = 0$, in (15) The number of base stations constructed that can be added to those already existing from the parent node is limited to control propagated energy and consumed electrical energy; in this way, restriction (16) controls and ensures that the coverage is successful over the planning area $\mathbb{A}$ through the parameters α^n, coefficients $\mathbb{W}^n_j$ and variables $\mathcal{C}^n$.

$$\sum_{i\varepsilon\mathbb{C}} Y_i^n \geq X_{s_j}^n \qquad ;\forall \quad n\varepsilon\mathbb{N}, \quad j\varepsilon\mathbb{A} \tag{13}$$

$$Y_i^n \geq Y_i^{p(n)} \qquad ;\forall \quad n\varepsilon\mathbb{N}, \quad i\varepsilon\mathbb{C} \tag{14}$$

$$\sum_{i\varepsilon\mathbb{C}} \left(Y_i^n - Y_i^{p(n)} \right) \leq \mathbb{K}^n \qquad ;\forall \quad n\varepsilon\mathbb{N} \tag{15}$$

$$\sum_{j\varepsilon\mathbb{A}} \mathbb{W}_j^n \ X_{s_j}^n \geq \alpha^n |\mathbb{A}| \mathcal{C}^n \qquad ;\forall \quad n\varepsilon\mathbb{N} \tag{16}$$

3.4. Fiber-optic restrictions for Fronthaul/backhaul

Restrictions (17–20) are responsible for ensuring a scalable deployment of the fiber-optic fronthaul/backhaul. Restriction (17) prevents fiber-optic links from being destroyed from parent nodes to child nodes in the MSPT. In (18, 19), it is sought to ensure the routing of all flows $\mathbb{F}$ from the m–active cells to the Central Office-OLT by means of fiber paths having a minimum distance. On the other hand, (20) enforces that the active links correspond to each of the m flows.

$$Z_{p,q}^n \geq Z_{p,q}^{p(n)} \qquad ;\forall \quad n\varepsilon\mathbb{N}, \quad p,q\varepsilon\mathbb{E} \tag{17}$$

$$\sum_{q|p,\, q\varepsilon\mathbb{E}_p^{OUT}} Z_{p,q}^{n,m} - \sum_{q|q,\, p\varepsilon\mathbb{E}_p^{INPUT}} Z_{p,q}^{n,m} = \mathbb{R}_{p,i} \ Y_i^n \tag{18}$$

$$\mathbb{R}_{p,i} = \begin{cases} 1, & if \quad i = OLT \\ -1, & if \quad i = m \\ 0, & if \quad i \neq OLT \wedge i \neq m \end{cases} \tag{19}$$

$$\sum_{m\varepsilon\mathbb{F}} Z_{p,q}^{n,m} \leqslant \mathcal{M} \ Z_{p,q}^n \qquad ;\forall \quad n\varepsilon\mathbb{N}, \quad p,q\varepsilon\mathbb{E} \tag{20}$$

3.5. Dimensioning of variables

In (21) we place the dimensioning of all the decision variables involved in the MILP. Finally **Table 2** summarizes all the variables, constants, coefficients and parameters used in the formulation of the MILP model.

$$\begin{aligned} & X_s \varepsilon \{0,1\}^{\mathbb{N}\times\mathbb{A}} \\ & Y \ \varepsilon \{0,1\}^{\mathbb{N}\times\mathbb{C}} \\ & Z \ \varepsilon \{0,1\}^{\mathbb{N}\times\mathbb{E}\times\mathbb{F}} \\ & \mathcal{C} \ \varepsilon \{0,1\}^{\mathbb{N}} \end{aligned} \tag{21}$$

3.6. MOA-FiWi algorithm

In order to treat medium or large instances of the problem, a new **M**ultistage **O**ptimization **A**lgorithm for **Fi**ber/**Wi**reless networks, called **MOA-FiWi**, has been proposed.

http://dx.doi.org/10.5772/intechopen.71781

Name	Domain	Interpretation
Sets		
$\mathbb{A}$	$\subseteq\Re^3$	Planning area, divided into pixels
$\mathbb{C}$	$\varepsilon\mathbb{Z}$	Set of candidate cells for coverage
$\mathbb{F}$	$\varepsilon\mathbb{Z}$	Set of m flows
Tree scenario		
$\mathbb{N}$		Set of MSPT nodes
$\mathbb{P}(n)$	$\varepsilon(0, 1]$	Probability at node n
$p(n)$	$\varepsilon\mathbb{N}$	Parent node at MSPT
Coefficients and parameters		
$\mathscr{M}$	$\varepsilon\Re >> 0$	It is a sufficiently large number $> \|\mathbb{F}\|$
$\mathbb{K}^n$	$\varepsilon\mathbb{Z}$	Construction limit at node n
α^n	$\varepsilon[0, 1]$	Coverage requirement parameter
$\mathbb{W}_j^n$	$\varepsilon[0, 1]$	Weight on a pixel in node n
$\widehat{\mathbb{I}}_j^n$	$\varepsilon\Re \geq 0$	Revenue per pixel at node n
$\widehat{\mathbb{C}}_i^{capex, n}$	$\varepsilon\Re \geq 0$	NPV of CAPEX in cell i at node n
$\widehat{\mathbb{C}}_i^{opex, n}$	$\varepsilon\Re \geq 0$	NPV of OPEX in cell i at node n
$\mathbb{D}_{p,q}^n$	$\varepsilon\Re \geq 0$	Distance for link $p \leftrightarrows q$ at node n
$\widehat{\mathbb{C}}_{p,q}^{capex, n}$	$\varepsilon\Re \geq 0$	NPV of CAPEX for link $p \leftrightarrows q$ at node n
$\widehat{\mathbb{C}}_{p,q}^{opex, n}$	$\varepsilon\Re \geq 0$	NPV of OPEX for link $p \leftrightarrows q$ at node n
Decision variables		
Y_i^n	$\varepsilon\{0, 1\}$	Cell i is active at node n
$X_{s_j}^n$	$\varepsilon\{0, 1\}$	UDAP j is covered at node n
$Z_{p,q}^n$	$\varepsilon\{0, 1\}$	Link $p \leftrightarrows q$ is active at node n
$\mathcal{C}^n$	$\varepsilon\{0, 1\}$	Fulfillment of coverage at node n

Table 2. Variables, coefficients, and parameters of the MILP.

The main optimization base of multistage optimization algorithm for fiber-wireless hybrid networks (MOA-FiWi) is through a set of actions and policies π to provide the maximum coverage to the UDAPs that carry the information of the users that benefit from the services provided by SG, SC and IoT. Therefore, it must be kept in mind that the amount of UDAP grows according to each MSPT path, according to this growth, the resource designation to form the FiWi network must horizontally scale in time and space.

The set ξ represents the universe of possible geographical locations over time for UDAPs within the planning region $\mathbb{A}$. Then, π_k a suitable policy depends on the values taken by the spatial locations of the UDAPs; $\xi : \xi' \subseteq \xi; \pi_k^*\left(\xi'\right)$, consequently the expected maximum benefit depends on the policies (22).

$$D^* : argmax\mathbb{E}\{\mathbb{R}\} = \mathbb{E}\left(\pi_k^*\right) = \tilde{\mathbb{R}}\left(\pi_k^*\right) \quad (22)$$

The policies are in charge of activating and optimally locating the base stations on candidate sites, for this a ***Modified Set Covered*** is used and fiber-optic links form a PON network through the help of a ***Modified Dijkstra*** in tree topology between the ONUs and the candidate site chosen to place the OLT, this location gives the reference point where the evolution of the FiWi network begins, this must be fulfilled for all nodes that form the MSPT, **Algorithm 1** details MOA-FiWi.

Algorithm 1. MOA-FiWi.

Step:1 **Generate:**
$MSPT(n, t)$
Step:2 **Generate:**
$\xi_0' \subseteq \xi$
Step:3 **Generate:**
$\pi_0^*\left(\xi_0'\right) \ \forall \ MSPT(n, t)$
Step:4 **Calculate:**
$\mathbb{E}\left(\xi_0'\right) = \tilde{\mathbb{R}}\{\pi_0^*\}$
Step:5 **Generate new:**
$\xi_{k+1}' = f_1\left(\xi_k', \xi\right)$
Step:6 **Modify:**
$\pi_{k+1}^* = f_2\left(\pi_k', \xi_k'\right) \ \forall \ MSPT(n, t)$
Step:7 **Apply:**
$Decision \ \ criterion \& Stopped$
Step:8 **Go to Step 5:**
$If \ \ criterion \ \ does \ \ not \ \ meet$
Step:9 **Return:**
$D^* : argmax\mathbb{E}\{\mathbb{R}\}$

---

4. Result analysis

To exemplify the operation of moa, a planning region $\mathbb{A}$ delimited by a graph $\mathbb{G}(\mathbb{V}, \mathbb{E})$ on a ***Delaunay Triangulation Space*** has been generated, within which a large number of UDAPs will be deployed, providing access to an average of ten to twenty users benefiting from the services provided by SG and SC. The coverage of the region will be distributed over four stages of time $t_k \rightarrow \{0, 1, 2, 3, 4\}$. **Figure 4(a)** shows a geographic distribution of the planning area which is a component of the subset ξ_0'. On the other hand, **Figure 4(b)** presents the MSPT for the four temporal stages.

In each node the projected population of UDAP is indicated and the value of the probability that measures the degree of uncertainty. At the end there are six scenarios, two considered as conservative, two as realistic and two as optimistic, being the point of break from year one.

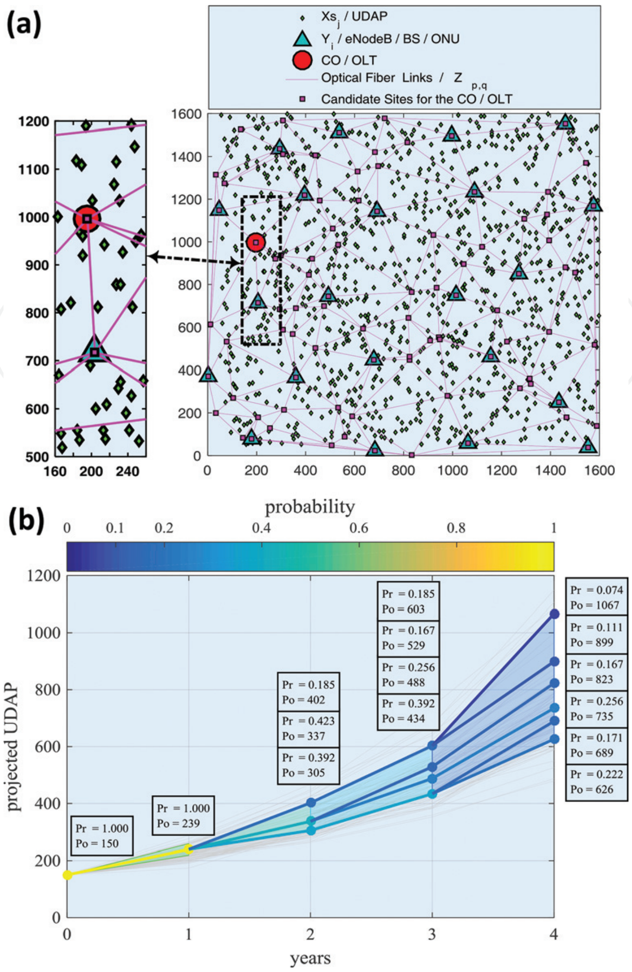

Figure 4. (a) Geographical distribution of an ξ_0' component. (b) MSPT for four stages of time.

Moreover, to obtain the reduced MSPT, one hundred paths were projected with $\mu = \mathbf{0,4}$ and $\sigma = \mathbf{0,1}$.

Table 3 summarizes the incomes and reference costs in US dollars, consulted with three telecommunications operators. These data are considered as input for MOA-FiWi. In addition,

Annual benefit per UDAP	$ 400,00
CAPEX OLT, with capacity for 1000 users, type XG-PON	$ 45.000,00
CAPEX eNodeB/ONU	$ 25.000,00
CAPEX per meter includes optical fiber, supports, pipes, and ducts	$ 15,00
Annual OPEX of eNodeB/ONU	$ 200,00
Annual OPEX per meter optical fiber	$ 1,20

Table 3. Revenues and costs considered in MOA-FiWi.

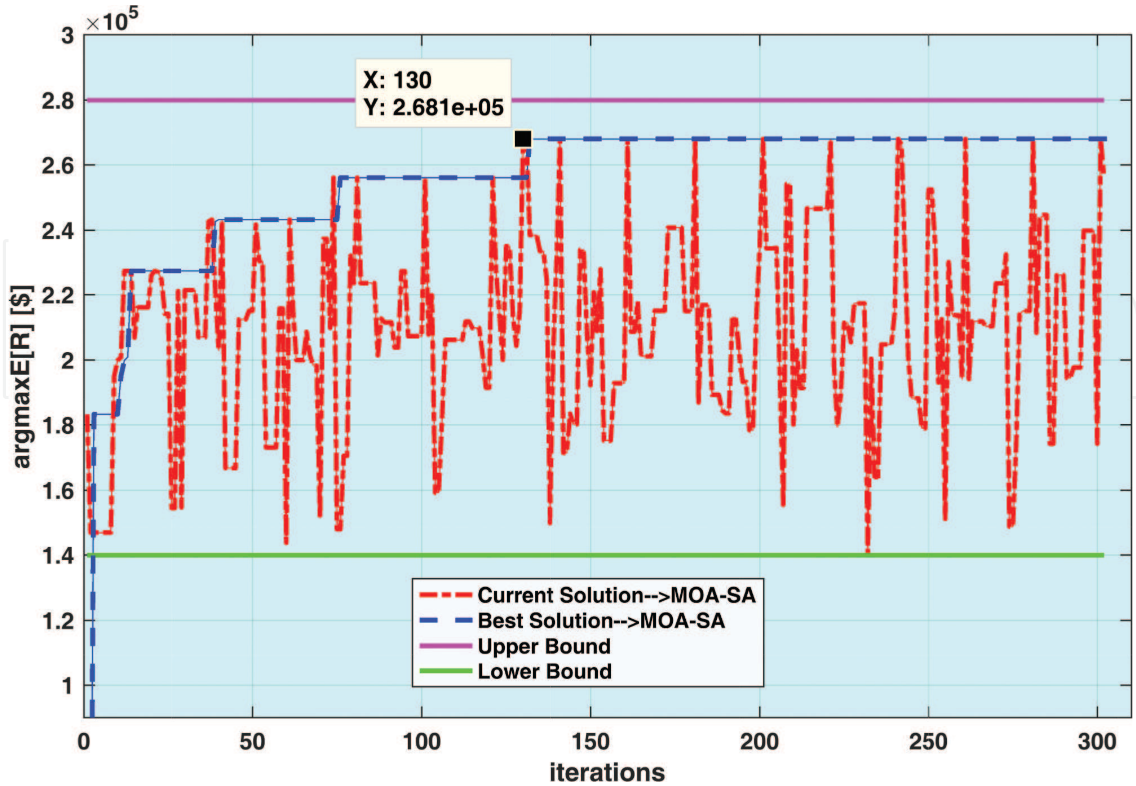

Figure 5. Solutions found by MOA-FiWi-SA.

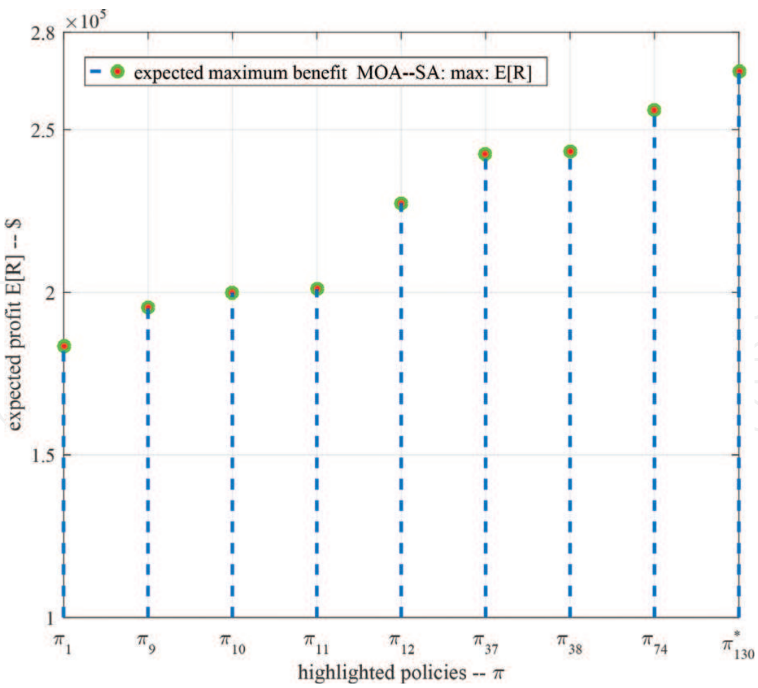

Figure 6. Featured policies found by MOA-FiWi-SA.

http://dx.doi.org/10.5772/intechopen.71781

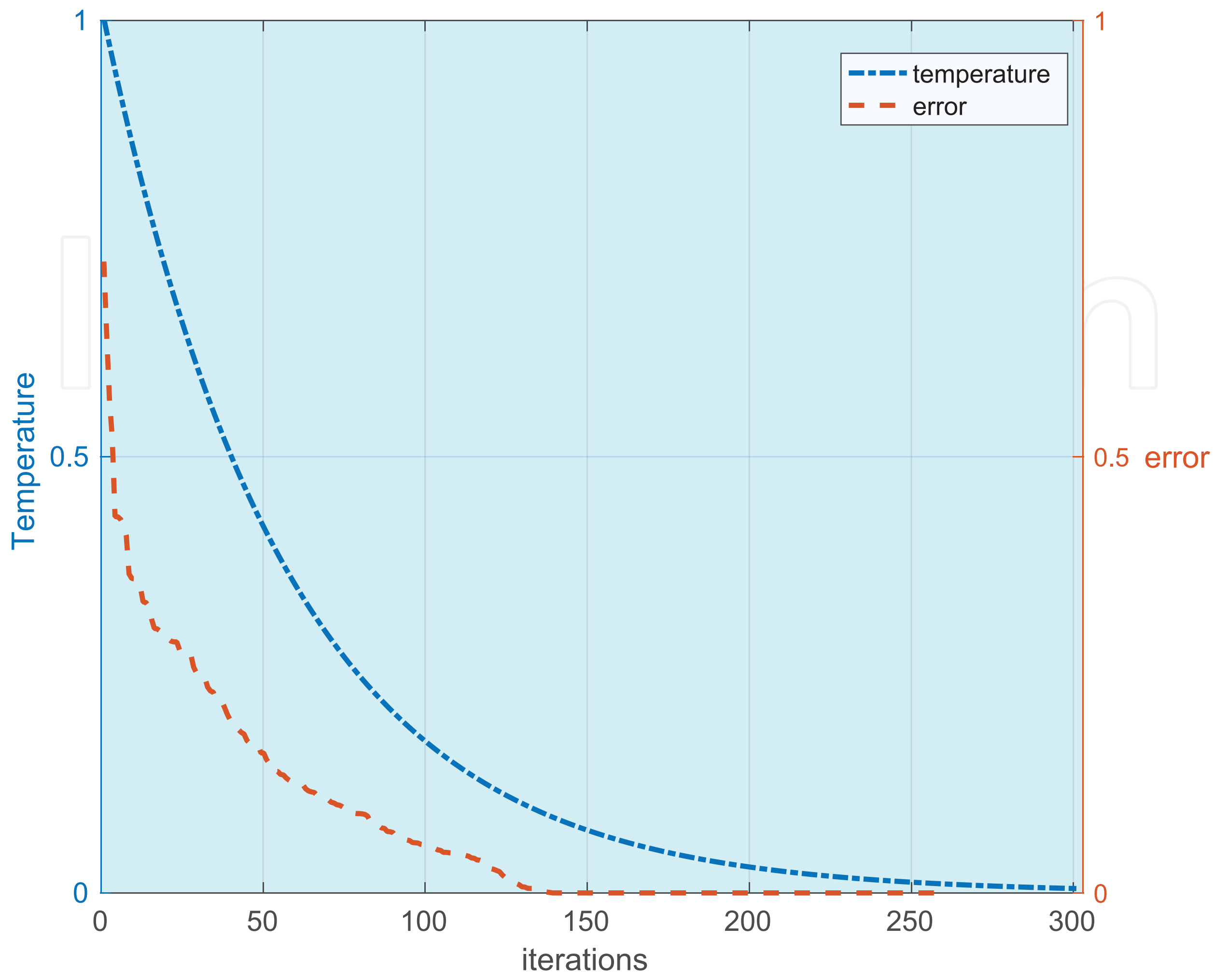

Figure 7. Cooling and error curve for *simulated annealing metaheuristic.*

the simulations were performed with a discount rate $r = 9,57\%$. **Figure 5** shows the evolution of the value D^*, over the search space by means of a ***simulated annealing metaheuristic***; the main policies are presented in **Figure 6**, and the maximum expected profit was achieved in the 130^{th} policy π^*_{130}, given 300 iterations.

Moreover, **Figure 7** exhibits the behaviors of temperature curve and error curve, in response to the optimization process using ***simulated annealing metaheuristic***; therefore, the behavior of MOA-FiWi is adequate, improving the feasible solutions found in each iteration.

The maximum expected benefit reached in 130^{th} policy on MSPT, where of the six stochastic paths after performing a decision-making analysis, paths with the best result were scenarios one and three. **Figure 8** presents topologies of these two scenarios.

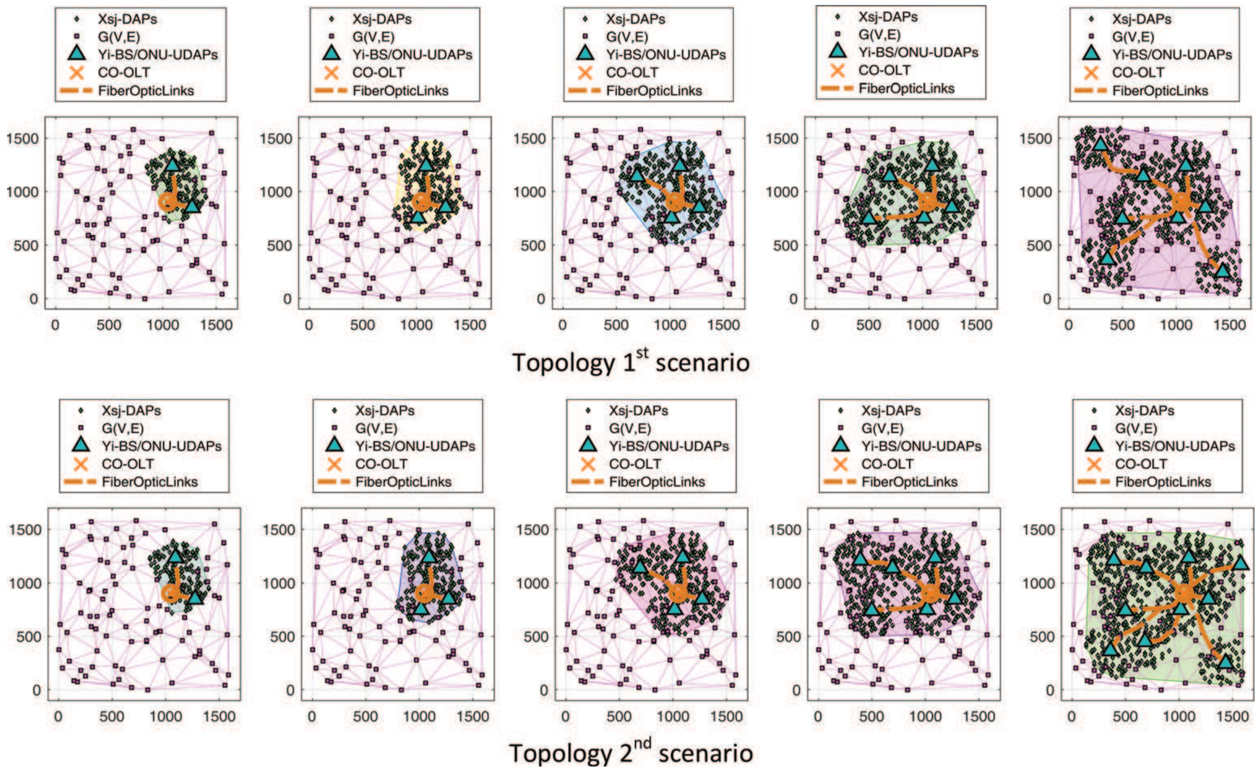

Figure 8. Best solution found by MOA-FiWi, 130th policy on MSPT.

5. Conclusions and future works

- SG, SC, and IoT applications require the power network to support a bidirectional flow of energy, so that users can interact with it to be able to deliver power to the system; in addition, a two-way flow of information between end users and service providers is required. For this reason the communications network that support services provided by SG, SC, and IoT plays a primary role, guaranteeing scalability, coverage, bandwidth, latency, reliability, security and privacy. These requirements must be fulfilled on all segments how are HAN, NAN, MAN and WAN.

- As services provided by SG and SC increase, the demand and coverage of IEDs increase with time, consequently communications infrastructure has to evolve and scale in parallel, to achieve this purpose the application of planning methods advanced under conditions of uncertainty would help to make decisions to network operators and improve their profitability and competitiveness for adapt changing market conditions.

- The main contributions of this work are the proposal of a planning model to treat scalability of FiWi networks, based on four phases, in addition a new mathematical optimization model MILP is proposed, through use of MSP, that it is destined to solve a problem that reaches a degree of complexity NP-Hard, however this is ideal as a tool to make decisions when communications network planning that presents uncertainty in demand growth, according different services that could be anchored over existing wireless networks such as are cellular networks. The optimization model focuses on achieving a scalable planning of fiber-optic network used as fronthaul/backhaul of wireless network, forming a FiWi hybrid network, which evolves over a space-time line.

- Being a stochastic problem, gives possibility and alternative of measuring the risk or benefit playing with actions and policies taken in each projected scenario, therefore, possible solutions can be approached from several points of view and not from one, as is case of deterministic planning model. MSPT allows it to find important breakpoints to take actions and policies that mark new forms of horizontal scalability in the topology of FiWi network that supports the services provided by SG, SC, and IoT.
- In order to deal computationally with multistage stochastic planning, an algorithm called MOA-FiWi has been proposed, where the optimization and stopping criterion were evaluated using simulated annealing metaheuristic. MOA-FiWi is based on optimization actions and policies, which provide horizontal scalability over a timeline and in presence of uncertainty; such situation occurs in real life when projects of expansion, updating or implementation of communications infrastructure are executed.
- On the other hand, obtained results reveal that there is a great sensitivity in maximum expected benefit, according to how the designation of wired and wireless resources in time and space is done to give maximum coverage to the users, with proposed model can be simulated to the problem from different points of view. As a result, a planning tool is available which helps in analysis to make decisions.
- Finally, for future works is intended to treat vertical scalability, with the purpose of improving performance and capacity of the system, in addition, to compare several technologies used in planning of FiWi networks, also try other metaheuristics that would help to explore the search space in a better way, to obtain feasible solutions.

Acknowledgements

This work is supported by the research groups GITEL of the Universidad Politécnica Salesiana, Cuenca, Ecuador, and the research group GIDATI of the Universidad Pontificia Bolivariana, Medellín, Colombia.

Glossary

AMI	advanced metering infrastructure
AMR	automated meters reader
AP	aggregation points
AWG	arrayed waveguide grating

BS	se stations
CAPEX	capital expenditure
CMM	cost minimization for meter data collection
CO	central office
DER	distributed energy resources
DG	distributed generation
DNOs	distribution network operators
eNodeB	enhanced node base station
EV	electric vehicles
FiWi	hybrid networks of optical fiber links combined with wireless links
GBM	geometric Brownian motion
GPRS	general packet radio service
HAN	home area network
HFC	hydrogen fuel cells
IED	intelligent electronic devices
IoT	internet of things
LTE	long term evolution
MAN	metropolitan area network
MCP	maximum coverage problem
MILP	mixed integer linear program
MOA-FiWi	multistage optimization algorithm for fiber-wireless hybrid networks
MSP	multistage stochastic programming
MSPT	multistage stochastic projection tree
MVNO	mobile virtual network operator
NAN	neighborhood area network
NPV	net present value
OLT	optical line termination
ONU	optical network unit
OPEX	operational expenditure
PAN	personal area network

PEM	polymer electrolyte membrane
PEV	plug-in electric vehicles
PHEV	plug-in hybrid electric vehicles
PLC	power line communication
PON	passive optical network
RN	remote nodes
SC	smart cities
SG	smart grids
SM	smart meters
SP	splitter
TIC	technologies of information and communication
UDAP	universal data aggregation point
WAN	wide area network
WHN	wireless heterogeneous network
WSN	wireless sensors network
WSP	Wiener stochastic processes

Author details

Arturo G. Peralta

Address all correspondence to: aperaltas@ups.edu.ec

Universidad Politécnica Salesiana, Cuenca, Ecuador

References

[1] Gao J, Xiao Y, Liu J, Liang W, Philip Chen CL. A survey of communication/networking in smart grids. Future Generation Computer Systems. 2012;**28**(2):391-404

[2] Sun Q, Ge X, Liu L, Xin X, Zhang Y, Niu R, Zeng Y. Review of smart grid comprehensive assessment systems. Energy Procedia. 2011;**12**:219-229. The Proceedings of International Conference on Smart Grid and Clean Energy Technologies ICSGCE 2011

[3] Usman A, Shami SH. Evolution of communication technologies for smart grid applications. Renewable and Sustainable Energy Reviews. 2013;**19**:191-199

[4] Aurzada F, Lévesque M, Maier M, Reisslein M. Fiwi access networks based on next-generation pon and gigabit-class wlan technologies: A capacity and delay analysis. IEEE/ACM Transactions on Networking. Aug 2014;**22**(4):1176-1189

[5] Bade MG, Toycan M, Walker SD. Cost and energy efficient operation of converged, reconfigurable optical wireless networks. Optical Switching and Networking. 2015;**18**(Part 1):71-80

[6] Coimbra J, Schütz G, Correia N. Energy efficient routing algorithm for fiber-wireless access networks: A network formation game approach. Computer Networks. 2014;**60**:201-216

[7] Ghazisaidi N, Maier M. Fiber-wireless (fiwi) access networks: Challenges and opportunities. IEEE Network. Jan 2011;**25**(1):36-42

[8] Lévesque M, Maier M. Probabilistic availability quantification of pon and wimax based fiwi access networks for future smart grid applications. IEEE Transactions on Communications. Jun 2014;**62**(6):1958-1969

[9] Liu J, Guo H, Nishiyama H, Ujikawa H, Suzuki K, Kato N. New perspectives on future smart fiwi networks: Scalability, reliability, and energy efficiency. IEEE Communications Surveys Tutorials. Secondquarter 2016;**18**(2):1045-1072

[10] Zhou J, Qingyang Hu R, Qian Y. Scalable distributed communication architectures to support advanced metering infrastructure in smart grid. IEEE Transactions on Parallel and Distributed Systems. Sep 2012;**23**(9):1632-1642

[11] Niyato D, Wang P. Cooperative transmission for meter data collection in smart grid. IEEE Communications Magazine. Apr 2012;**50**(4):90-97

[12] Gungor VC, Sahin D, Kocak T, Ergut S, Buccella C, Cecati C, Hancke GP. Smart grid technologies: Communication technologies and standards. IEEE Transactions on Industrial Informatics. Nov 2011;**7**(4):529-539

[13] Fan Z, Kulkarni P, Gormus S, Efthymiou C, Kalogridis G, Sooriyabandara M, Zhu Z, Lambotharan S, Chin WH. Smart grid communications: Overview of research challenges, solutions, and standardization activities. IEEE Communications Surveys Tutorials. First 2013;**15**(1):21-38

[14] Galli S, Scaglione A, Wang Z. Power line communications and the smart grid. In: 2010 First IEEE International Conference on Smart Grid Communications. Oct 2010. pp. 303-308

[15] Feng Z, Yuexia Z. Study on smart grid communications system based on new generation wireless technology. In: 2011 International Conference on Electronics, Communications and Control (ICECC). Sep 2011. pp. 1673-1678

[16] Overman TM, Sackman RW. Smart grid control systems communications architecture. In: 2010 First IEEE International Conference on Smart Grid Communications. Oct 2010. pp. 19-24

[17] Bu S, Yu FR, Liu PX, Zhang P. Distributed scheduling in smart grid communications with dynamic power demands and intermittent renewable energy resources. In: 2011 IEEE International Conference on Communications Workshops (ICC). Jun 2011. pp. 1-5

[18] Xiao Y. Communication and Networking in Smart Grids, volume 1 of Taylor & Francis Group. 1st ed. CRC Press; 2012. https://www.taylorfrancis.com/books/e/9781439878729

[19] Tuttle DP, Baldick R. The evolution of plug-in electric vehicle-grid interactions. IEEE Transactions on Smart Grid. Mar 2012;**3**(1):500-505

[20] Kaebisch S, Schmitt A, Winter M, Heuer J. Interconnections and communications of electric vehicles and smart grids. In: 2010 First IEEE International Conference on Smart Grid Communications. Oct 2010. pp. 161-166

[21] Bouhafs F, Mackay M, Merabti M. Links to the future: Communication requirements and challenges in the smart grid. IEEE Power and Energy Magazine. Jan 2012;**10**(1):24-32

[22] Inga E, Cespedes S, Hincapie R, Cardenas CA. Scalable route map for advanced metering infrastructure based on optimal routing of wireless heterogeneous networks. IEEE Wireless Communications. Apr 2017;**24**(2):26-33

[23] Bhatt UR, Chhabra A, Fiber-wireless RU. (fi-wi) architectural technologies: Asurvey. In: 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT). Mar 2016. pp. 519-524

[24] La Oliva AD, Perez XC, Azcorra A, Giglio AD, Cavaliere F, Tiegelbekkers D, Lessmann J, Haustein T, Mourad A, Iovanna P. Xhaul: Toward an integrated fronthaul/backhaularchitecture in 5g networks. IEEE Wireless Communications. Oct 2015;**22**(5):32-40

[25] Huang X, Wang S. Aggregation points planning in smart grid communication system. IEEE Communications Letters. Aug 2015;**19**(8):1315-1318

[26] Erol-Kantarci M, Mouftah HT. Energy-efficient information and communication infrastructures in the smart grid: A survey on interactions and open issues. IEEE Communications Surveys Tutorials. Firstquarter 2015;**17**(1):179-197

[27] Inga E, Hincapie R. Matched channel allocation for advanced metering infrastructure based on cognitive mobile virtual network operator. IEEE Latin America Transactions. April 2016;**14**(4):1780-1785

[28] Li P, Guo S, Cheng Z. Joint optimization of electricity and communication cost for meter datacollection in smart grid. IEEE Transactions on Emerging Topics in Computing. Dec 2013;**1**(2):297-306

[29] Yu R, Zhang Y, Gjessing S, Yuen C, Xie S, Guizani M. Cognitive radio based hierarchical communications infrastructure for smart grid. IEEE Network. September 2011;**25**(5):6-14

[30] Yu R, Zhang Y, Chen Y. Hybrid spectrum access in cognitive neighborhood area networks in the smart grid. In: 2012 IEEE Wireless Communications and Networking Conference (WCNC). April 2012. pp. 1478-1483

[31] Huang J, Subramanian VG, Agrawal R, Berry R. Joint scheduling and resource allocation in uplink ofdm systems for broadband wireless access networks. IEEE Journal on Selected Areas in Communications. February 2009;**27**(2):226-234

[32] Challita U, Al-Kanj L, Dawy Z. On lte cellular network planning under demand uncertainty. In: 2014 IEEE Wireless Communications and Networking Conference (WCNC). April 2014. pp. 2079-2084

[33] Milling C, Subramanian S, Shakkottai S, Berry R. Routing over multi-hop wireless networks with non-ergodic mobility. In IEEE INFOCOM. April 2009;**2009**:2079-2087

[34] Lin B, Tapolcai J, Ho PH. Dimensioning and site planning of integrated pon and wireless cooperative networks for fixed mobile convergence. IEEE Transactions on Vehicular Technology. Nov 2011;**60**(9):4528-4538

[35] Aalamifar F, Shirazi GN, Noori M, Lampe L. Cost-efficient data aggregation point placement for advanced metering infrastructure. In: 2014 IEEE International Conference on Smart Grid Communications (SmartGridComm). Nov 2014. pp. 344-349

[36] Maier M, Levesque M, Ivanescu L. Ng-pons 1 & 2 and beyond: The dawn of the uber-fiwi network. IEEE Network. Mar 2012;**26**(2):15-21

[37] Karimi B, Namboodiri V. On the capacity of a wireless backhaul for the distribution level of the smart grid. IEEE Systems Journal. June 2014;**8**(2):521-532

[38] Peralta Sevilla A, Inga Ortega E, Hincapie R. Fiwi network planning for smart metering based on multistage stochastic programming. IEEE Latin America Transactions. Dec 2015;**13**(12):3838-3843

[39] Peralta-Sevilla A, Inga E, Cumbal R, Hincapié R. Optimum deployment of fiwi networks using wireless sensors based on universal data aggregation points. In: IEEE Colombian Conference on Communication and Computing (IEEE COLCOM 2015). May 2015. pp. 1-6

[40] Peralta-Sevilla AG, Amaya-Fernández F, Hincapie R. Multiservice hybrid wdm/tdm-pon dimensioning using a heuristic method. In: 2014 IEEE Colombian Conference on Communications and Computing (COLCOM). Jun 2014. pp. 1-5

[41] Trigeorgis L. Real Options: Managerial Flexibility and Strategy in Resource Allocation. The MIT Press; 1996. https://mitpress.mit.edu/books/real-options

[42] Ramirez W, Harmantzis FC, Tanguturi VP. Valuing wireless data services solutions for corporate clients using real options. International Journal of Mobile Communications. Feb 2007;**5**:259-280

[43] Beltran-Royo C, Escudero LF, Monge JF, Rodriguez-Ravines RE. An effective heuristic for multistage linear programming with a stochastic right-hand side. Computers & Operations Research. 2014;**51**:237-250

[44] Wang T, De Neufville R. Building real options into physical systems with stochastic mixed-integer programming. In: Proceedings of the 8th Real Options Annual. 2004. pp. 1-35

[45] Shapiro A, Dentcheva D, Ruszczynski A. Lectures on Stochastic Programming: Modeling and Theory. 2nd ed. Philadelphia, PA, USA: Society for Industrial and Applied Mathematics; 2014. http://epubs.siam.org/doi/book/10.1137/1.9780898718751

[46] Eisenblätter A, Schweiger J. Multistage stochastic programming in strategic telecommunication network planning. Computational Management Science. 2012;**9**(3):303-321

[47] Dixit AK, Pindyck RS. Investment under Uncertainty. Princeton University Press; 1994. https://press.princeton.edu/titles/5474.html

[48] Shreve SE. Stochastic Calculus for Finance II. Springer; 2004. http://www.springer.com/la/book/9780387401010#aboutAuthors

[49] Growe-Kuska N, Heitsch H, and Romisch W. Scenario reduction and scenario tree construction for power management problems. In: 2003 IEEE Bologna Power Tech Conference Proceedings, Vol. 3; Jun 2003. pp. 1-7

[50] Peters L. Real Options Illustrated. SpringerBriefs in Finance. Cham: Springer International Publishing; 2016

IntechOpen