Planning Wi-Fi Access Points Activation in Havana City: A Proposal and Preliminary Results

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Abstract. The availability of Wi-Fi connection points or hotspots in places such as parks, transport stations, libraries, and so on is one of the key aspects to allow people the usage of Internet resources (to study, work or meet). This is even more important in Central America and Caribbean countries where the deployment of huge cost infrastructure (like optical fiber) to provide Internet access at home is not envisaged neither in the short or mid term. And this is clearly the case in Havana, Cuba.

This contribution presents the problem of planning the Wi-Fi access points activation, where each point can have different signal power levels and availability along the time. Due to power consumption constraints, it is impossible to have all the points activated simultaneously with maximum signal strength.

The problem is modelled as a dynamic maximal covering location one with facility types and time dependant availability. A metaheuristic approach is used to solve the problem by using an Algorithm portfolio and examples on how solutions can be analyzed (beyond the coverage provided) are shown.

Keywords: Signal levels · Wi-Fi access points

1 Introduction

In a recent report from the International Telecommunication Union (ITU) (United Nations specialized agency for information and communication technologies) [8], one can read:

> ... Internet use continues to grow globally, with 4.1 billion people now using the Internet, or 53.6% of the global population. However, an estimated 3.6

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billion people remain offline, with the majority of the unconnected living in the Least Developed Countries where an average of just two out of every ten people are online.

In all regions of the world, households are more likely to have Internet access at home than to have a computer because Internet access is also possible through other devices. While 93% of the world's population lives within reach of a mobile broadband (or Internet) service, just over 53% actually uses the Internet.

According to the World Bank' DataBank (an analysis and visualisation tool that contains collections of time series data on a variety of topics)[1] Cuba has the following figures:

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Individuals using the Internet (% of population)	15,90	16,02	21,20	27,93	29,07	37,31	42,98	57,15	...
Fixed broadband subscriptions (per 100 people)	0,03	0,04	0,04	0,05	0,07	0,07	0,13	0,30	0,87
Mobile cellular subscriptions (per 100 people)	8,93	11,70	14,94	17,69	22,38	29,45	35,18	40,69	47,39

Although Internet usage and mobile cellular subscriptions are steadily increasing, they are still quite low. Also in the rest of Central America and Caribbean countries the deployment of huge cost infrastructure (like optical fiber) to provide Internet access at home is not envisaged neither in the short or mid term. So deploying wireless connection is one of the steps needed to enlarge Internet usage among the people.

These Wi-Fi access points (WAPs), provide signal to the users if they are within its radius of signal. That means, the location of the WAP is very important for the satisfactory access to Internet. With this approach, the questions of where to locate the WAPs and how to plan their activation/deactivation can be treated as special cases of location problems.

A classic location problem is the maximal covering location problem (MCLP) proposed by Church and ReVelle in [3]. The MCLP aims to locate a limited number of facilities in order to maximize the coverage over a set of demand nodes. The term "facility" should be understood in a wide sense, ranging from warehouses, bus stops or, as in our case, WAPs.

Several examples of the application of MCLP for placing wireless devices may be found in the literature. In [12], one the first contributions in telecommunications scenarios was proposed. A greedy-add method was used over the MCLP and the set covering location problem (SCLP) to design a network of cellular mobile communication system.

[1] https://databank.worldbank.org/.

In [9] the MCLP was used to locate wireless routers, taking into account a central tower with a main signal. The routers share its signal, therefore they must be located at a certain distance from each other to maintain the signal strength. In [11] a variant of MCLP was proposed to locate routers and gateways. The model has capacity constraint to guarantee the correct flow on the connections. In [1] a multi-objective MCLP was proposed to locate the nodes in a wireless network with bandwidth capacity constraints. The objectives were: to maximize the coverage, to minimize the bandwidth usage, and to minimize the cost of the network and the interference signal. The NSGA-II algorithm was used to obtain the Pareto-front of the problem. In [2] an extension of MCLP was used to locate a set of access points in a wireless network in order to maximize the total offloaded traffic in an area. A greedy adding algorithm with substitution was used to solve the problem. In [7] a fuzzy MCLP was proposed to locate Wi-Fi antennas in Havana City. The fuzzy constraint describe uncertain information about the availability of antennas due to meteorological events near the coast. A parametric approach was used to solve the fuzzy problem. In [4] a variant of DMCLP to locate flying base stations was proposed. These bases move according to the change in population density over time. The bases have user connectivity capacity constraints.

Let's now consider the following situation. Havana City is exploring ways to provide Internet access to their citizens. There is information about the population density and how they may move. During a day the number of users requiring an Internet connection can change. For example, in the early morning there are less users than the afternoon. Besides, there is a set of deployed WAPs that provide a wireless signal, which provide coverage up to a maximal distance, named the coverage radius. A WAP has different signal levels or strength (e.g. strong, medium and low), that affects the coverage radius and just one level can be activated.

Due to energy saving policies, it is impossible to activate all of the available WAPs with a strong signal level (which would be the obvious solution to the problem). For example, during the early morning all signal levels may be available, since it is when the overall power consumption in the city is lower. However, at night, only the lowest signal level can be used, since it is where the highest energy consumption is perceived. The previous situation can be modelled using the location problem presented in [10]: the dynamic maximal covering location problem with facilities types and time dependant availability (DMCLP-FT).

In this contribution we apply the DMCLP-FT to manage the WAPs activation in Havana, Cuba. The paper is organized as follows: Sect. 2 describes the DMCLP-FT. Section 3 presents the DMCLP-FT to activate a set of WAPs in Havana City, Cuba and comments the principals results and analysis. Finally, we present the conclusions of our contribution.

2 Dynamic Maximal Covering Location Problem with Facility Types and Time Dependant Availability

Several features should be considered when solving the problem but we highlight two of them: 1) WAPs may not have available all the different signal levels and 2) the demand at a geographic area may change over the time. For example, the number of users can decreased or increased depending on the schedule, in the morning there more users on-line than the early morning.

These features can be modelled using a generalization of DMCLP presented in [10]: the dynamic maximal covering location problem with facility types and time dependent availability (DMCLP-FT). The mathematical formulation of the DMCLP-FT, applied to the WAPs activation, is the follows:

- i, I: the index and set of user nodes.
- j, J: the index and set of WAPs.
- t, T: the index and number of time periods.
- k, K: index and number of signal levels.
- a_{it}: population or number of users at node i in period t.
- d_{ij}: the shortest distance (or time) from demand node i to Wi-Fi access j.
- p_k: number of WAPs to be activated with level k.
- S_k: coverage radius provided by a signal level k. It is the minimum distance (or time) between a node and WAP to be considered as covered.
- $W_{jtk} \in \{0; 1\}$: a binary variable, 1 if the WAP j has available the level k in period t, 0 otherwise.
- $N_{itk} = \{j | d_{ij} \leq S_k$ and $W_{jtk} = 1\}$: set of potential WAPs that can cover the users at node i if a WAP with level k is available in the location j in period t.
- $X_{jtk} \in \{0; 1\}$: a binary variable, 1 if a WAP at location j is activated with level k in period t, 0 otherwise.
- $Y_{it} \in \{0; 1\}$: a binary variable, 1 if the node i is covered by one or more WAPs in period t, 0 otherwise.

The objective function is:

$$Maximize : Z = \sum_{t \in T} \sum_{i \in I} a_{it} Y_{it} \tag{1}$$

Subject to:

$$Y_{it} \leq \sum_{k \in K} \sum_{j \in N_{itk}} X_{jtk}, \forall i \in I, \forall t \in T \tag{2}$$

$$\sum_{t \in T} \sum_{j \in J} X_{jtk} = p_k, \forall k \in K \tag{3}$$

$$\sum_{k \in K} p_k < J * T \tag{4}$$

$$\sum_{t \in T} \sum_{j \in J} W_{jtk} > p_k, \forall k \in K \tag{5}$$

$$\sum_{t \in T} \sum_{k \in K} W_{jtk} \geq 1, \forall j \in J \tag{6}$$

$$\sum_{k \in K} X_{jtk} \leq 1, \forall j \in J, \forall t \in T \tag{7}$$

$$\sum_{k \in K} X_{jtk} \leq W_{jtk}, \forall j \in J, \forall t \in T \tag{8}$$

The objective function (1) is aimed at maximizing the coverage of the nodes (sets of users). Constraint (2) shows that a node can be covered if an activated WAP with level k in period t belong to set N_{itk}. Constraint (3) shows that the number of WAPs with level k to activate must be equal to p_k. Constraint (4) shows that the total of WAPs with level k that will be activated should be less than the total of available WAPs.

Constraint (5) shows that the availability of WAP with level k must be greater than the number of WAPs with level k that will be activated in all time periods. Constraint (6) shows that a WAP must have at least one available signal level in some period t. Constraint (7) shows that a WAP j can be activated with only one level k. Finally, constraint (8) shows that a WAP can be activated with an available level k.

3 The Case in Havana City, Cuba

In this section we describe the problem of planning the WAPs activation for a whole day in Havana City, Cuba. The WAPs can adjust their signal levels (signal power), thus affecting the covered area. The stronger the signal level is, the higher the covered area (the higher the number of users served). Due to energy saving policies in Cuba, it is not possible to have the already deployed WAPs working simultaneously with a strong signal. Thus, in short, the problem is to determine which WAP (and when) should be activated and with which signal level.

There are several factors that may influence the availability of a given signal level in a schedule. Firstly, the consumption of electrical energy. At night, the energy consumption is higher and therefore, it is not possible to use strong signal levels, since it consumes more energy.

Secondly, geographical features during working hours (morning and afternoon). During these schedules of the day, activities are carried out that need WAPs with a certain signal level. For example, cultural or economic activities, where the signal levels suitable for a WAP are known.

Finally, at early morning, the energy consumption is low, so there are no restrictions on the signal levels.

As the user may notice, within a day the availability of the signal levels per access point would change, depending on the access point location.

In this case study we aim at planning the activation just for one day divided in four stages.

3.1 Problem Information

Part of the data available for the problem is taken from [7]. We include $T = 4$ time periods that represent times of a day: $t = 1$ is early morning, $t = 2$ is morning, $t = 3$ is afternoon and $t = 4$ is night. There are $I = 956$ areas or user nodes and for each node i and time period t there is a demand estimation or number of users to be covered a_{it}. At period $t = 1$, the values a_{i1} are taken from the data set used in [7]. Then, the demand a_{it} for $t = 2, 3, 4$ was randomly generated using values between $[MIN(a_{i1}) - 1; MAX(a_{i1}) + 1]$. The total demand/users to be covered for each time period are $\{35350, 146820, 145646, 144771\}$ for to $t = 1$ (early morning), $t = 2$ (morning), $t = 3$ (afternoon) and $t = 4$ (night) respectively.

There are $J = 200$ WAPs deployed, and $K = 3$ signal levels for each WAP j are considered. The availability of the signal levels is as follows: at $t = 1$ every WAPs can be activated with any signal level. At $t = 2$ and $t = 3$, 70% of J have available the low power level $k = 1$, 50% with medium power level $k = 2$ and 30% with strong power level $k = 3$. Please note that a WAP may have available more than one type of signal during a time period.

Finally, at $t = 4$ the WAPs can only be activated with a low power signal level $k = 1$.

For each signal level k, the corresponding coverage radius S_k is calculated as follows. Firstly, it is computed the $maxD = max(d_{ij})$. Then, for each signal level, the coverage radii are defined as: $S_1 = maxD \times 0.02, S_2 = maxD \times 0.03$ and $S_3 = maxD \times 0.04$.

In a day, we can activate $p_1 = 30$ WAPs with low signal, $p_2 = 18$ with medium signal and $p_3 = 12$ with a strong signal.

3.2 Solving Strategy

As we assume that imprecision can be present in the problem' information, we propose to solve it by means of an approximate method. Instead of choosing just a single strategy (like an isolated metaheuristic), we focus in an Algorithm portfolio (AP) presented in [6]. The AP is composed by different metaheuristics, that are used in a cooperative way to obtain good solutions for optimization problems. Here, the portfolio is composed by: a Hill climbing, an Evolutionary strategy and a basic Genetic algorithm, both with a population size = 10 and a Simulated annealing with and initial temperature $t_{initial} = 10000$, a cooling rate $\alpha = 0.9$, a number of iterations at each temperature $iter = 50$ and a final temperature $t_{final} = 0.005$ [5].

A solution of the DMCLP-FT can be represented as an integers' list where the value 0 means that the WAP is off, k means that the WAP is activated with level k and -1 means that the WAP has not any signal level in that period.

As we are not aiming at performing comparisons among several metaheuristics method, we omit more details about the implementation used.

3.3 Results

The AP method was run 30 times. Figure 1 displays the best solution obtained. The overall coverage was 370314 (78.36%). The activated WAPs have a circle that represents the radius corresponding to the signal level used. It is interesting to observe the number of users covered at each time period.

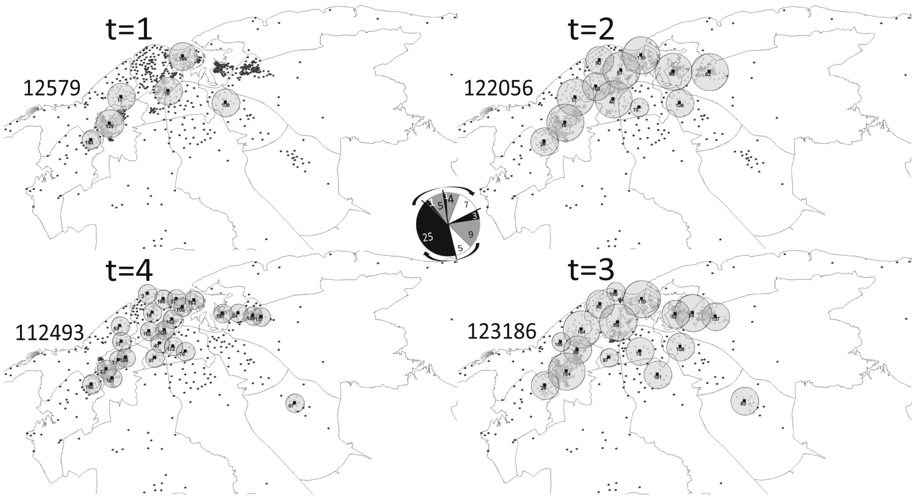

Fig. 1. Description of the best solution after 30 runs.

At the center of Fig. 1 a pie chart appears showing the number of WAPs activated per time period. The black/grey/white series indicates the level $k = 1, 2, 3$ respectively.

At period $t = 1$ there are 6 WAPs activated: 1 WAP with level $k = 1$ and 5 with level $k = 2$. At the period $t = 2$, 12 WAPs were activated: 1 WAP with level $k = 1$, 4 with $k = 2$ and 7 with $k = 3$. At period $t = 3$, 17 WAPs are activated: 3 WAPs with level $k = 1$, 9 with level $k = 2$ and 5 with level $k = 3$ were activated. Finally, at period $t = 4$, a higher number of WAPs is used because they can only use a low level signal strength.

Figure 1 also shows the geographical distribution of the WAPs, together with their coverage radii (associated with the circle radii). In the solution, we can see that the WAPs were activated in areas where there is high concentration of users to be connected. It can be observed that at period $t = 1$, just a few WAPs were activated. This period corresponds with the early morning, where the demand is lower. At $t = 2$, WAPs with medium and strong signals are used. At $t = 3$, the covered area is quite similar but with a different configuration for the WAPs. By the end of the day ($t = 4$), the covered demand is reduced due to the use of WAPs with low level signals.

As we made 30 runs of the portfolio, we analyse a set of different solutions with a similar value of demand covered. Figure 2 shows a graphic where we can see the behaviour in the number of activated WAPs during a day. We denoted each level using the previous scheme. For visualization purposes, just 14 solutions (out of 30) achieving different coverage values are selected. The solutions are sorted by the coverage value (solution 14 is the one showed in Fig. 1).

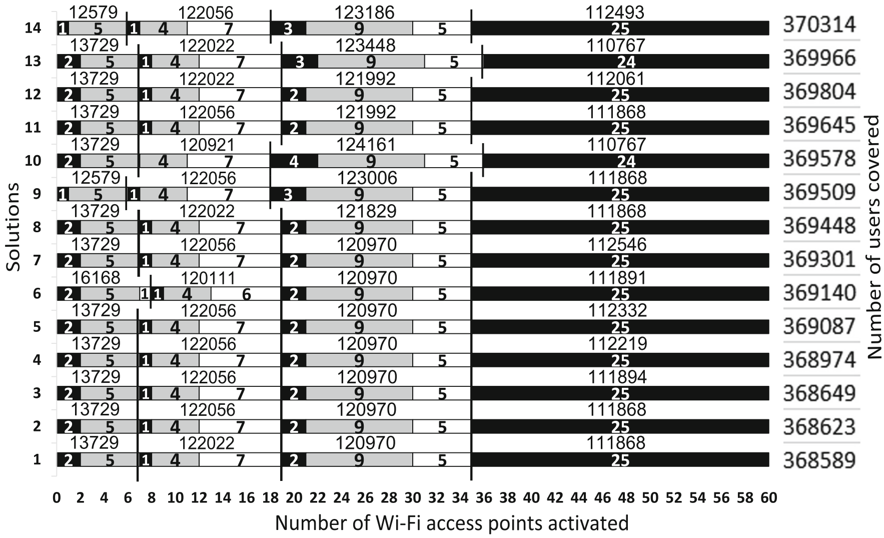

Fig. 2. Distribution of activated WAPs and their types for a day. Solutions have a different value of coverage.

For each solution we indicate the number of users covered. The end of the periods are marked by lines and for each one we show the number of users covered. For each series we can see the number of WAPs that were activated.

In general, we can see that the variability among the solutions is low. The graph provides insight on how the coverage is attained. The use of WAPs in the period $t = 1$ was not prioritized. The algorithm makes use of WAPs with level $k = 1$ in the last period $t = 4$, and not in the previous periods. An example is the best solution (14), which provides new and varied combinations that resulted in a better planning. The activated WAPs with level $k = 3$ were the most used in the period $t = 2$.

It is interesting to note that solution 9 uses the same distribution of levels as the best solution. When we explore the location of the WAPs we observed that both solutions differ in 16 activated WAPs. The selection used by the best solution allowed to obtain a greater number of users covered.

We can also note that solution 13 has the same number of WAPs activated in the period $t = 3$ as the solution 14. However, solution 13 has more users covered in that period than the solution 14. We could obtain an even better solution than solution 14, if we keep the distribution of WAPs activated in the periods $t = 1$, $t = 2$ and $t = 4$ of solution 14, and replace the distribution of $t = 3$ obtained in solution 13.

In general, in the period $t = 1$, we can see few difference between the solutions, in terms of the number of users covered. You can also note that the solution 6 was the only one that used a WAP with level $k = 3$ at $t = 1$, but it does not yield to better results. In the best solutions, the use of low power level $k = 1$ is almost neglected in the first periods. From solutions 2 to 5, we can see that the main difference was in the period $t = 4$, where the quality of the distribution of the WAPs with signal level $k = 1$ made the difference.

4 Conclusions and Future Research

In this contribution we propose a model and an algorithm to deal with the planning of WAPs activation in Havana. A dynamic maximal covering location problem with facility types and time dependant availability were used to model the situation.

As we consider the data available as imprecise, we discard solving the problem with an exact solver. Instead, we applied an Algorithm portfolio composed by classic metaheuristics that allows us to obtain *a set of good solutions*. We explore several ways to analyse them, ranging from simple coverage values, to the type of signal levels used in the WAPs, and to the WAPs geographical distribution.

Several venues are opened now. One is regarding how the quality of a solution should be assessed. In our opinion, a sort of max-min approach can be useful: to maximize the minimum level of coverage provided at any time of the day. Second is to consider some activation/deactivation costs for the WAPs. Both aspects are under study.

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