# Modeling and Optimization of Heterogeneous Wireless LAN

Pavel Pechac, Martin Klepal
Department of Electromagnetic Field
Czech Technical University in Prague
Prague, Czech Republic
pechac@ieee.org

Ana Martinez
Strix Systems, Inc.
26610 Agoura Road, Suite 110
Calabasas, CA 91302, USA
ana.martinez@strixsystems.com

***Abstract*— A sophisticated approach to automated prediction for the optimal layout and quantity of WLAN access points to achieve the desired network parameters is introduced. The algorithms were implemented in web-based software for RF planning of complete wireless local area system with multiple radio frequency technologies (IEEE 802.11a, 802.11b/g, and Bluetooth) based on mesh topology. The implemented optimization method based on Evolution Strategies offers easy specification of various network aspects and QoS requirements (hotspots of various technologies, proffered areas near Ethernet ports and power outlets, throughput, number of concurrent users, etc.). The first few months of operation and usage in many real-world scenarios have shown good performance and appropriate accuracy. The application is also able to model site-specific coverage and capacity of the wireless network using semi-empirical propagation models.**

***Keywords - WLAN; optimization; Evolution Strategies; propagation prediction; mesh topology***

## I. Introduction

As the popularity of wireless Local Area Networks (WLANs) increases, networks based on various technologies and topologies are becoming more widely deployed in indoor environments. With increasing demands on QoS (user coverage, data throughput, RF interference, etc.) the software planning and optimization of these wireless networks has become an ever more important issue.

A unique WLAN solution that addresses these needs is offered by Strix Systems, Inc. Access/One™ Network [1] is a complete wireless local area system. It supports multiple radio frequency technologies – 802.11a, 802.11b/g, and Bluetooth – so that up to three access points (APs) can be stacked together to form a node of the network. The network employs a mesh topology with 802.11a wireless backhaul. A more detailed description of the system is beyond the scope of this paper. However, we will focus on the RF planning software called Architect/One™ [2], which is used as part of setting up the Access/One Network.

The Architect/One software is a web-based application for planning the WLAN network (Fig. 1). The application is able to predict site-specific coverage and capacity of the wireless network. For propagation modeling a modified semi-empirical COST231 Multi-Wall Model [3] has been utilized, with employment of a more robust ray-based model called Motif Model [4] under consideration. Optionally, a simple empirical One Slope Model [3] can be used when no information on walls and obstacle placement is available.

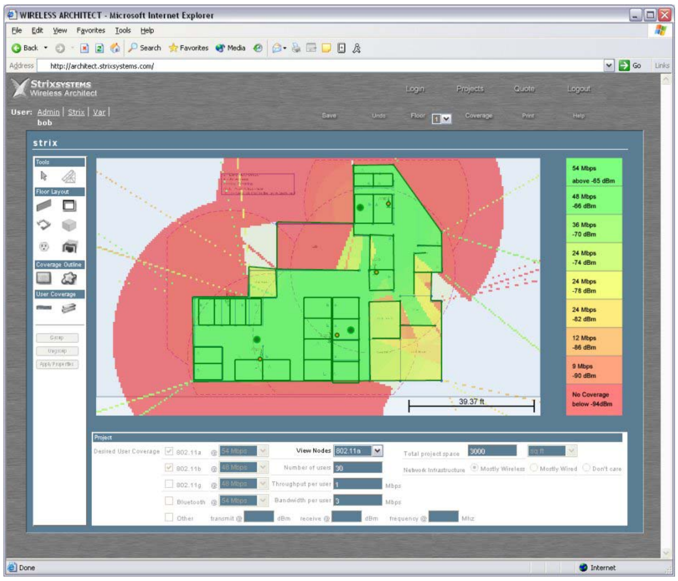

Figure 1. Architect/One software screenshot

A unique feature within Architect/One is the automated prediction and placement for the optimal layout and quantity of access points to achieve the desired network parameters. To do this, a user defines hotspot areas for each technology with the network requirements. Then the optimization process determines the quantity and placement of the access points by taking into account these various aspects. The task is not trivial at all. This paper is dedicated to an introduction of the optimization algorithm.

## II. Optimization Method

### *A. Optimization Logic*

The implemented method allows specification of various optimization aspects to meet the needs of a particular working environment. An input floor plan (Fig. 2) includes the location of main obstacles and layout of hotspots of various

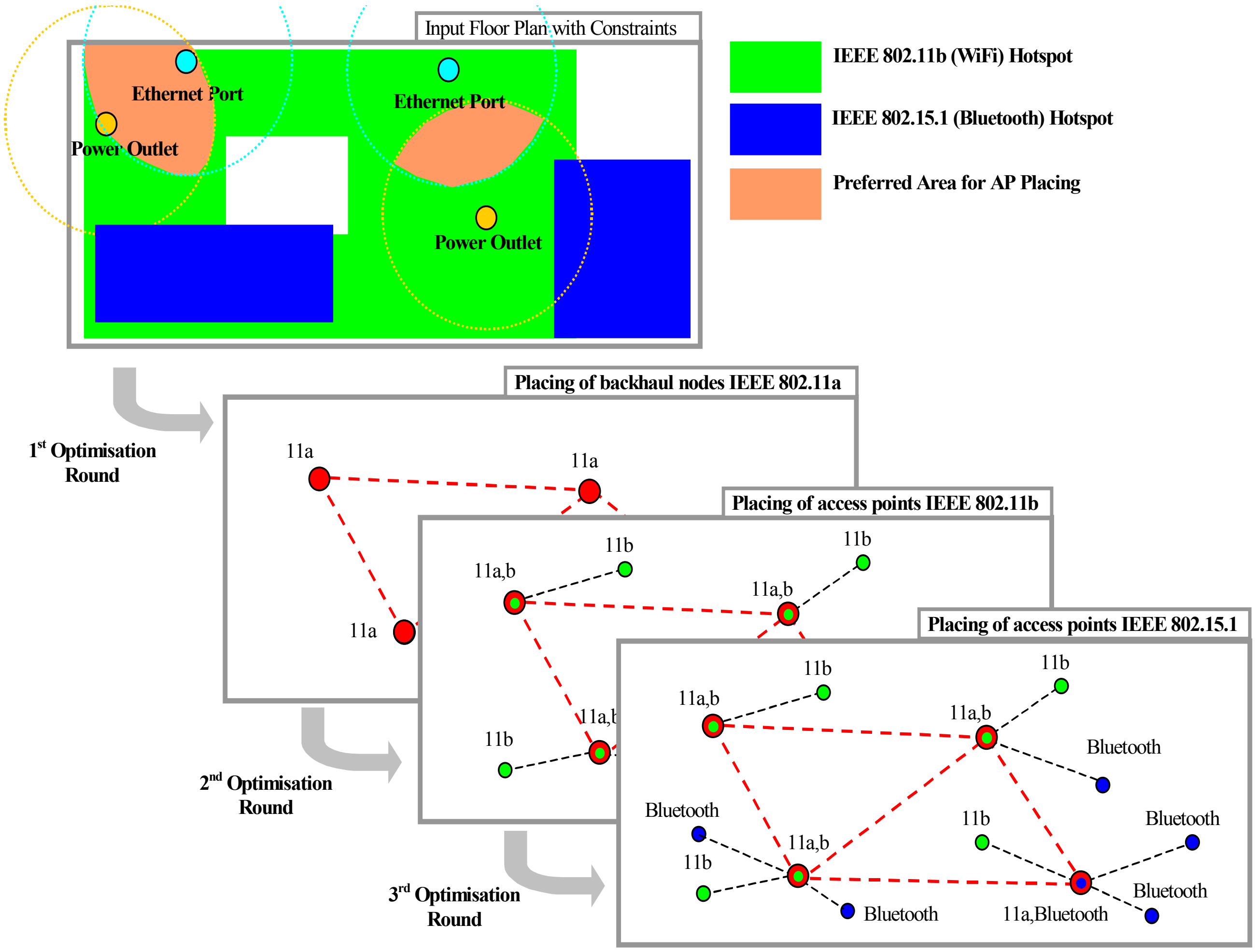


Figure 2. Example of automated process from an input floor plan to optimal layout of a heterogeneous WLAN

technologies. It may consider also positions of Ethernet ports and power outlets in order to force access point placement into preferred areas reducing additional wiring. The coverage requirements are given by received signal strength (RSS) threshold within a hotspot based on desired throughput and number of concurrent users.

It is obvious that the structure of the presented heterogeneous WLAN becomes very complex as the required hotspot areas for each technology are spreading and overlapping throughout a building. To partly diffuse the optimization complexity the process of APs placement consists of optimization rounds corresponding to the number of technologies:

- The role of the first round is always building the backhaul wireless mesh (IEEE802.11a) ensuring a sufficient network throughput and uplink connection for the sublayers to the fixed network. At least one AP must be in a reach of an Ethernet port. The locations of 11a APs are considered as preferred AP (node) locations for the following rounds.
- In the second round, the WiFi sublayer (IEEE802.11b) is formed to ensure a sufficient throughput in the relevant hotspot area.
- Finally, the third round (if desired) arranges the layout of Bluetooth APs (IEEE802.15.1) to cover specified Bluetooth hotspots.

Generally, the goal of the optimization algorithm is to find minimum number of APs and their optimal locations to meet the user input requirements as close as possible.

### B. *Evolution Strategies*

Despite splitting the optimization process into several individual rounds the optimization for a large building is still such a complex task that conventional approaches such as the basic Down Hill Simplex method or the exact Conjugate Gradient method are incapable of finding the optimal solution. The optimization problem is in fact such that evolutionary computation techniques are best suited to finding the optimal AP location.

The two best-known evolutionary computation methods are Evolution Strategies (ES) [5] and Genetic Algorithms (GA) [6]. To find an appropriate method we tested and compared both. Finally, ES were selected with respect to their computational efficiency (number of necessary fitness evolutions) and reliability in finding the global optimum in a fitness landscape. Many variants of ES were evaluated with suitable parameters and mutation strength control that were able to find a global minimum in various test scenarios. The ES that were selected: (5.500)-ES (5 parents, 500 children) with

- $\sigma$-Self-Adaptation mechanism
- coordinate-dependent mutation strengths $\sigma_n$
- learning parameter $\tau = 0.15$

Making the distinction of coordinate-dependent mutation strengths was significant because it helps to avoid a prematurity of convergence for parameters with a weak influence on the fitness function.

### C. *Structure of Used Chromosome*

The sustainable problem representation within evolution strategies needs the application of a chromosome structure with variable length (Fig.3), which depends on the actual number of APs in the solution represented by the chromosome. There can be two kinds of APs in the solution:

- APs placed into preferred positions. The preferred positions are specified by the user or are given by the position of nodes in the upper network layer. For example the preferred position for WiFi APs in the second optimization round would be the positions of backhaul nodes from the first optimization round. Locations of Ethernet ports and power outlets are also considered defining preferred areas.
- APs freely placed anywhere to meet predefined requirements.

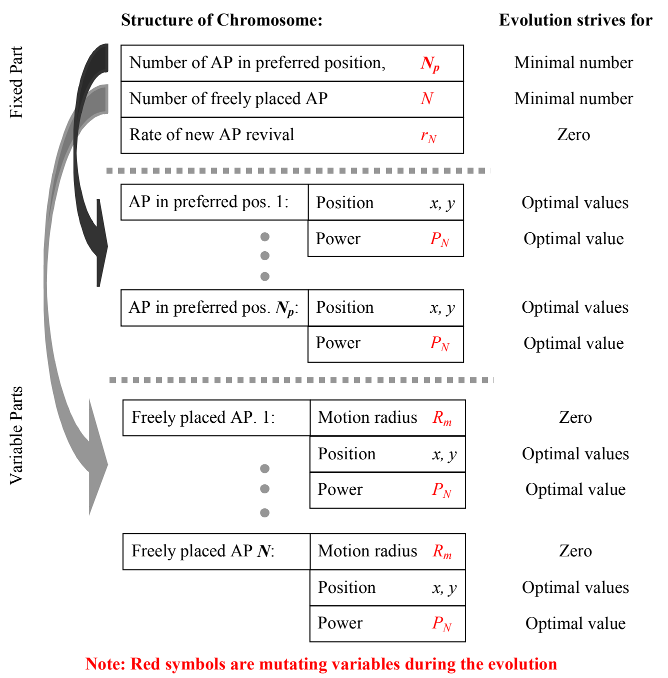


Figure 3. Structure of the implemented chromosome with variable length

The chromosome structure can be divided into three parts. The first, fixed part comprises three variables driving mainly the number of APs in the actual solution. The second and third parts having variable length consist of both kinds of APs. The only one parameter optimized for an AP in a preferred position is its radiation power in contrast to the freely placed AP, whose position is also optimized besides its power.

### D. *Fitness Function*

The problem of the access point location optimization is quite intricate mainly due to difficulties in defining a fitness (cost) function. The fitness function should incorporate many suitably weighted factors, such as user coverage, number and position of APs and APs interference to produce a multidimensional fitness landscape, which encourages an optimization process convergence.

We found it beneficial in the process convergence that the different factors change their weights during the optimization process in a particular fashion. Such emphasis of certain variables profiles different stages in the optimization process. The function of the first two stages is to achieve a required user coverage and network throughput by a minimal number of APs, while the function of the third stage is to attain a well-proportioned load of all APs, for example. The extent of the influence of various factors on the fitness function during the optimization is shown in Fig.4.

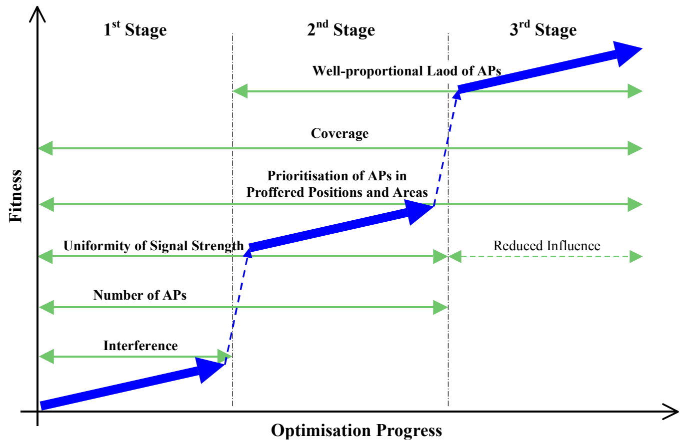


Figure 4. Extent of main factors having influence on the fitness function during the optimisation stages

## III. PERFORMANCE OF THE OPTIMIZATION ALGORITHM

As mentioned above, the optimization has been developed as part of the design software Architect/One™, which is accessible by users from any web browser. We paid therefore particular attention not only to the robustness of the optimization but also to its speed. The duration of the complete process depends naturally on the scale of the building and the number of various technologies dictating the number of optimization rounds. We found that a common processing time for rather smaller scenarios was less than a few seconds and for the largest ones usually did not exceed one minute. Of course it is a tradeoff between the speed and the optimization performance. The more time is given to the algorithm to find a solution the better is the result for a very complex task. Balance between computation time and optimization robustness as well as the fitness function behavior were empirically tuned based on many real world testing scenarios.

The performance of the algorithm is demonstrated on the following three examples. Generally, the signal propagation model is the main limiting factor for the optimization performance. Fig. 5 shows a very easy task for the optimization. Even so the area of the hotspot is huge and of complicated shape, the optimization gives always the same number and same locations of APs providing a uniform coverage as required. The computation time is just few seconds. That is thanks to the open space indoor environment. Regular indoor environments (open space or more or less regularly placed obstacles like walls, partitions, etc.) are suitable for the used semi-empirical Multi-Wall Model [7].

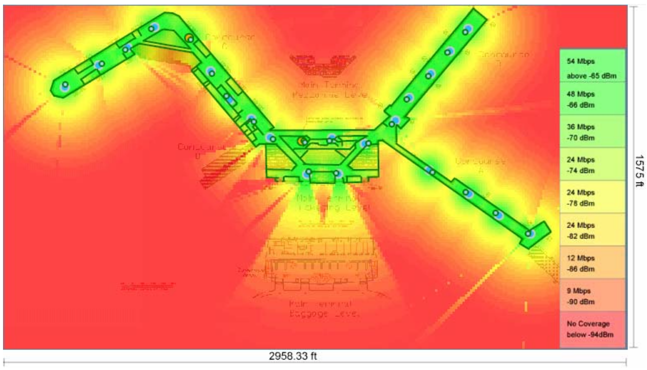


Figure 5. Example of the optimization result - APs placed to cover an airport hotspot area; calculated coverage is given in color scale

The problem is when there are thick walls or other significant obstacles like elevator shafts in the scene. The model is not able to consider reflections and diffractions of electromagnetic wave but only the insertion loss of the obstacle. The result is usually underestimation of signal strength behind the obstacle while the shadow is covered thanks to reflections and diffractions in reality. The case is demonstrated in Fig. 6.


Figure 6. Example of the optimization result (blue circles are the APs)

Quite regular structure of the floor is broken by several small strong attenuating obstacles (dark rectangles). Blue region represents a “restriction zone” where no AP can be placed. In spite of that the optimization can handle this task giving the acceptable results within a minute. The difference to the preceding case is that the different results can be obtained when running the algorithm several times since there are many solutions meeting the hotspot coverage requirements.

The third example (Fig. 7) shows the case where the optimization completely fails giving no acceptable results after several minutes of computation. There is lot of small rooms closed by thick walls with high attenuation factor assigned. As the optimization is trying to cover every single spot within the hotspot more and more APs are introduced preventing convergence of the procedure. The solution here would be a correction of used wall attenuation factors or splitting the hotspot to several smaller ones to reduce the problem complexity.

Figure 7. Example of the optimization result

## IV. SUMMARY

A sophisticated optimization algorithm based on evolutionary strategies was developed and has been implemented in the web-based RF planning application, which allows simultaneous usage by several users. The algorithm enables the automated design of heterogeneous WLAN layouts with minimum input requirements and computation time. The first few months of operation and usage in many real-world scenarios have shown good performance and appropriate accuracy. The ongoing development of the application is focused on improvement of the propagation prediction models and further tuning of the optimization fitness function.

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