Indoor IEEE 802.11g Radio Coverage Study

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***Abstract*— Even though the wireless coverage inside buildings is widely studied, there are many deployments that are not optimal. An accurate design, not only allows more radio coverage inside the building, but could allow cost savings if we are able to reduce the number of access points that are used to implement the solution. In this paper, we will show a research study about the optimum location of access points inside the building of the Polytechnic University of Valencia (UPV) in order to provide better wireless Internet access to the students. The paper provides a comparative study for different Service Set Identifiers (SSIDs) (are currently available at the university). We will also compare them analytically. Finally we will obtain the mathematical expressions that allow us to model their behavior and we will see how the signals propagate following a very peculiar pattern.**

Keywords-radio coverage; indoor study, WLAN; IEEE 802.11g.

I. INTRODUCTION

Today, wireless networks are widely used in companies and universities as a support to the wired network. These allow the user easy access to all services provided by the company's network and usually allow Internet access.

When attempting to develop indoor wireless networks, many problems arise such as losses due to the walls, refractions over objects arranged randomly on the site or losses due to the use of different types of construction materials that cause different types of losses (brick, metal, glass, etc.) [1, 2].

Moreover to these issues, we should add the fact that the building interiors are almost never uniform making it very difficult to foresee in advance exactly what is the radio coverage of the wireless network [3].

It is necessary to have a correct and optimal design, in order to offer multiple additional services such as indoor positioning, object location, object tracking, etc. [4]. Moreover wireless coverage systems are being studied in other research fields such as Wireless Sensor Networks (WSN) [5].

In this paper, we analyze the behavior of the wireless signals from access points (APs) located in the Centre of resources for the research and learning (CRAI) of The Polytechnic High School of Gandia, of the Polytechnic University of Valencia (UPV). The obtained measurements will allow us to know the received signal strength evolution in function of the distance to the APs.

The rest of this paper is structured as follows. Section 2 shows some related works about radio coverage. Section 3 presents the scenario and the tools used to perform our measurements. Section 4 shows the result of the measurements in coverage maps. Section 5 makes a comparative study of the three analyzed signals on each floor. The analytical study and the equations which expressed this behavior are shown in Section 6. Finally, Section 7 shows the conclusion and future works.

II. RELATED WORKS

There have been many studies of wireless coverage, both empirically [6] and analytically [7]. Concretely, in [7], the authors performed an analytical study about the AP location and channel assignment. The treatment of these keys separately can lead to optimal designs. Authors propose an integrated model that addresses both aspects simultaneously in order to find a balance to optimize both objectives.

M. Kamenetskyt et al. [8] examine the methods for obtaining a position close to the optimal entry points and evaluate their performance in a typical center or campus environment. System performance is evaluated by an objective function, which aims to maximize the coverage area and signal quality. The optimization algorithms used are a subjective function on a discrete search space, which significantly reduces the complexity inherent to the problem. Numerical results show that random search algorithms, can lead to good solutions. However, the convergence of simulated travel speed depends largely on the development of simulation parameters and a good parameters selection.

Kaemarungsi and Krishnamurthy [4] studied the features of the IEEE 802.11-based WLANs and analyze the data in order to understand the underlying features of location fingerprints. They pointed out that the user's presence should be taken into account when collecting the location fingerprint for user related location-based service.

J. Lloret et al. [10, 11] showed studies about an empirical coverage radio model for indoor wireless LAN design. This model has been tested on a vast number of buildings of a great extension area with over 400 wireless APs in order to get the results successfully. The objective of the model is to facilitate the design of a wireless local area network WLAN using simple calculations, because the use of statistical methods takes too much time and it is difficult to implement in most situations. The proposed model is based on a derivation of the field equation of free propagation, and takes into account the structure of the building and its materials.

Sendra et al. [12] presented a comparison of the IEEE 802.11a/b/g/n variants in indoor environments in order to know which is the best technology. This comparison is made in terms of received signal strength indicator (RSSI), coverage area and measurements of interferences between channels.

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Figure 1. Map of Polytechnic high school of Gandia.

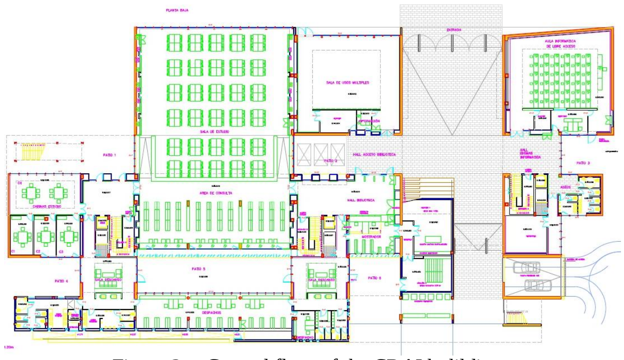

Figure 2. Ground floor of the CRAI bulilding.

Figure 3. First floor of the CRAI building

Figure 4. Second floor of the CRAI building

III. SCENARIO DESCRIPTION AND USED TOOLS

The CRAI was built in 2007. It belongs to the Polytechnic high school of Gandia. It has 3 floors, where different services for the students are offered. It contains the library, some computer labs and open access classrooms. Figure 1 shows the location of this space. It is the H building

Now, we are going to describe the scenario where the measurements have taken from the wireless networks and the hardware and software used to perform our research.

A. The building

The ground floor (see Fig. 2) contains the information desk, staff offices, the library and a large study room with a consultation area and several classrooms for group study. There is a multipurpose room where events and exhibitions are sometimes held.

On the first floor (see Fig. 3) we can find several computer labs, classrooms to perform Final Degree Projects, group study rooms and individual study rooms.

The second floor (see Fig. 4) has the magazine and journal library, the video library, some computer labs and some professor offices.

B. Description of UPV Wireless Network

Polytechnic high school of Gandia is a campus of the UPV and shares the 4 networks with the main campus: EDUROAM, UPVNET2G, UPVNET and UPV-INFO. Each one of these allows the university users to access Internet and the university resources.

- UPVNET: Wireless network with direct connection to all the resources of the UPV. It requires a wireless card with Wi-Fi Protected Access (WPA) and Wi-Fi Protected Access II (WPA2).
- UPVNET2G: Direct network connection to all resources of the UPV and the Internet. It requires a wireless card with WPA/WPA2.
- EDUROAM: This wireless network is widely deployed in universities and research centers in Europe. It provides internet access to all of their members. The users need the user name and password of their home institution. It requires a wireless card with WPA/WPA2. EDUROAM only provides Internet access.
- UPV-INFO: This wireless network is designed to provide information about how the wireless network should be configured. It uses private IP addressing and it does not allow Internet access. A second connection is needed to access Internet and UPV resources. This second connection is a Virtual Private Networking (VPN). It should only be used by very old computers that do not support WPA encryption.

In this paper, we will analyze three of these networks. They are UPVNET, UPVNET2G, EDUROAM.

C. Used software and hardware

In order to carry out this work, several measurements have been done along the three floors of the CRAI. We have used different network devices to perform the measurements:

- Linksys WUSB600N [13]: Is a USB wireless device that was used to gather the measurements. It is able to capture signals from the IEEE 802.11a/b/g/n variants. Its power transmission is 16 dBm for all variants and the receiver sensitivity is about -91dBm in both internal antennas. The transmission power consumption is less than 480mA and it consumes 300mA in the reception mode.

- Laptop: It was used to take the coverage measurements. It has a dual core processor with 2 GHz per core and 2 Gbyte of RAM Memory. It has Windows Vista.
- Cisco Aironet 1130AG (AIR-AP1131AG-E-K9) [14]: This AP is used in all floors of the building. Its data rate can reach up to 54 Mbps. It can work at 2.4 GHz or 5 GHz, with a maximum distance between 100m to 122m indoors (as a function of the IEEE 802.11a or IEEE 802.11g variant). The maximum distance for outdoor environments, is between 198 m to 274 m. It can be powered by PoE (Power over Ethernet).

In order to capture the received signal at each point of the building, we used the following program:

- InSSIDer [15]: Is a free software tool that detects and controls the wireless networks and the signal strength in a graphical way. This program lists all detected wireless networks and provides their details as Service Set Identifier (SSID), Media Access Control address (MAC address), channel, RSSI, network type, security, speed and intensity of the signal and also allows the control of the quality of the signal.

IV. COVERAGE RESULTS

We have measured the walking area, where students and university staff can access. Bathrooms, exterior stairways, storage, etc are excluded. In order to perform this work, a grid of 4 meters x 4 meters has been drawn in each floor. This allows us to make measurements of the different networks in the same places. The laptop was located at a height of 100 cm above the ground.

A. Ground floor

This subsection shows the signal coverage measured on the ground floor. There are 5 APs that cover the entire plant. There are four places with the highest coverage level (the values are higher than -50 dBm). We highlight 2 rooms, Room A, the multipurpose room, and Room B, the computer room (see Figs. 5, 6, and 7). The AP located outside the wall of the computer room provides coverage levels below -70 dBm inside the classroom for all three cases.

Fig. 5 shows the coverage area and levels of UPVNET wireless network at the ground floor. Room A presents signal strength of -90 dBm due to the signal attenuation generated when crossing several walls.

Fig. 6 shows the coverage area for the UPVNET2G wireless network on the ground floor. Three places with higher signal strengths than -50 dBm can be seen. These places correspond to the location of APs. The multipurpose room has a very low coverage on the left side because the signal is greatly attenuated because it crosses several walls.

Fig. 7 shows the value of signal strength for EDUROAM wireless network on the ground floor. Again, there are three places with the high signal strength in excess -50 dBm, which correspond to the location of APs. In this case, more than half of the room B has signal strength levels below -70dBm.

B. First floor

This subsection shows the signal strength measured on the first floor. In this case, there are 4 APs that cover the entire plant. There are 4 places with the highest signal strength (higher than -50dBm).

Fig. 8 shows the signal strength for UPVNET wireless network on the first floor. The rooms at the left side have low radio coverage because the AP is not located in the correct place. The offices at the right side have also very poor signal strength because they are very close to the stairs and they suffer signal attenuation rather important.

Fig. 9 shows the UPVNET2G wireless network signal strength on the first floor. We can see that in the classroom on the left hand is not well covered because of the AP position. It is located on the right hand of the wall. The offices from the bottom right also have very poor coverage, because they are very close to the stairs, which generate significant signal attenuation.

Fig. 10 shows the EDUROAM signal strength on the first floor. In this case, we can see the same effect as in the other cases, but, moreover, there are tables in the study area (center of the picture), with a low signal strength (lower than -90 dBm).

C. Second floor.

This subsection shows the signal strength measured on the second floor. The floor is covered by 4 APs. They offer a good coverage across most of the surface.

Fig. 11 shows the signal strength for UPVNET wireless network on the second floor. In this floor, there is good radio coverage across the whole plant.

Fig. 12 shows the signal strength of UPVNET2G on the second floor. This signal is correctly broadcasted through the floor and its signal strength levels are sufficient to cover the working places.

Fig. 13 shows the signal strength of EDUROAM wireless network on the second floor. The signal on this floor is very good.

After having analyzed the radio coverage images, it is easy to see that the behavior of the signal strengths for each floor is quite similar, with small variations. The received signal strength is very low in bathrooms and toilets. This is because the amount of water pipes and copper tubes in the walls which produce the signal attenuation. We have also found low signal strength levels in the stairwells. The stairs usually have metal framework and a foundation which prevents the spreading of the signal.

V. COMPARATIVE STUDY

In this section, we compare the signals of the same plant. Fig. 14 shows the three signals from the ground floor. UPVNET2G provides better signal strength levels than UPVNET and EDUROAM. Signal strengths from the first floor are shown in Fig. 15. UPVNET2G is the network that presents the highest signal strengths. UPVNET and EDUROAM have similar behavior although there are some points where EDUROAM signal is better.

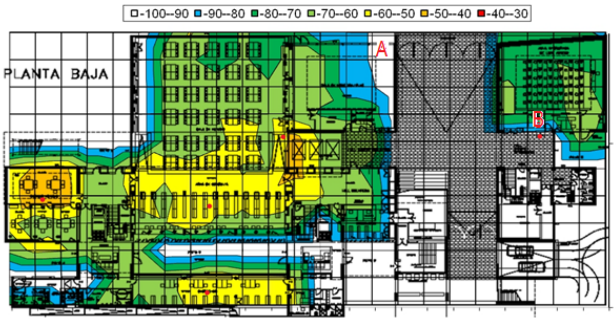

Figure 5. Radio coverage map of the ground floor for UPVNET

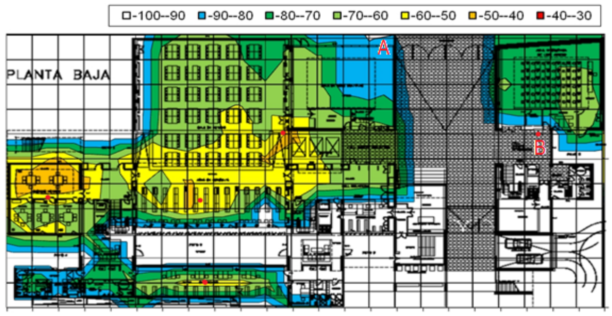

Figure 6. Radio coverage map of the ground floor for UPVNET2G

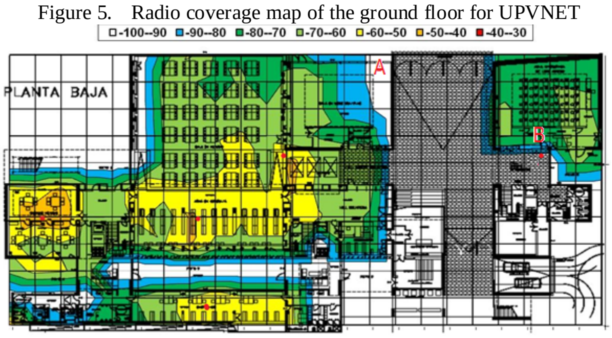

Figure 7. Radio coverage map of the ground floor for EDUROAM

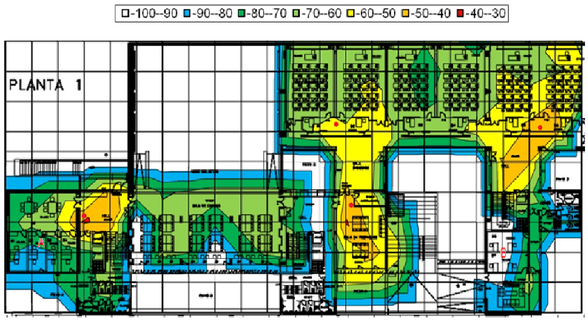

Figure 8. Radio coverage map of the first floor for UPVNET.

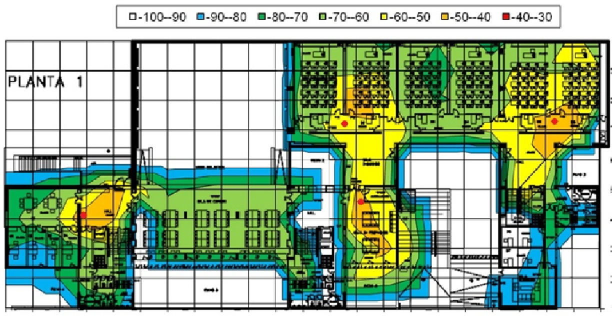

Figure 9. Radio coverage map of the first floor for UPVNET2G

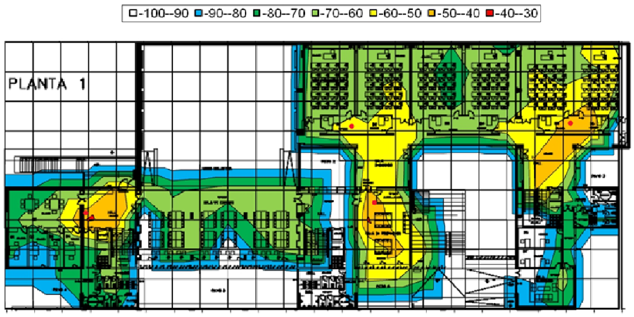

Figure 10. Radio coverage map of the first floor for EDUROAM

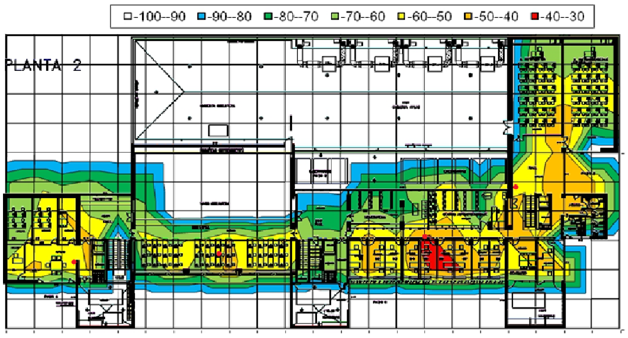

Figure 11. Radio coverage map of the second floor for UPVNET

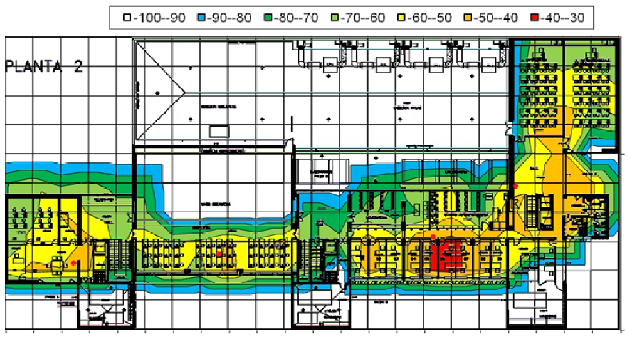

Figure 12. Radio coverage map of the second floor for UPVNET2G

Fig. 16 shows the behavior of signal strengths of the second floor. UPVNET2G and EDUROAM have identical behavior from 3 meters to around 10 meters, but from 0 to 3 meters and 10 meters to 12 meters, EDUROAM signal strength is better. The lowest signal strength is presented by UPVNET all the time. Keeping in mind all graphs, it is easy to conclude that the wireless network that provides the best signal strength level is UPVNET2G.

VI. ANALYTICAL STUDY

After analyzing the above figures, we can estimate the behavior of the wireless signals in indoor environments. Therefore, this section shows how the signal strength varies depending on the distance to the AP.

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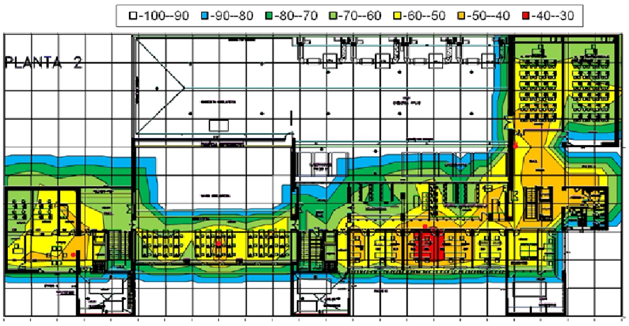

Figure 13. Radio coverage map of the second floor for EDUROAM

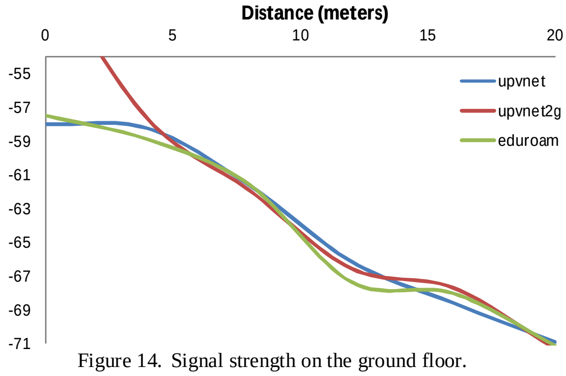

Figure 14. Signal strength on the ground floor.

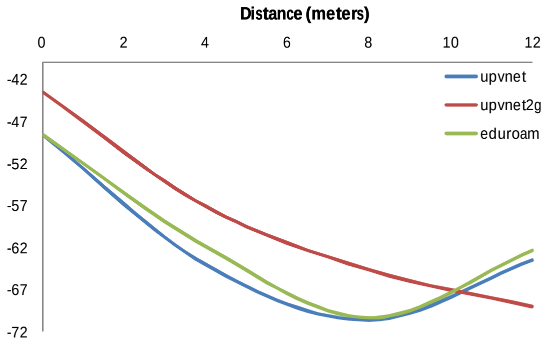

Figure 15. Signal strength on the first floor.

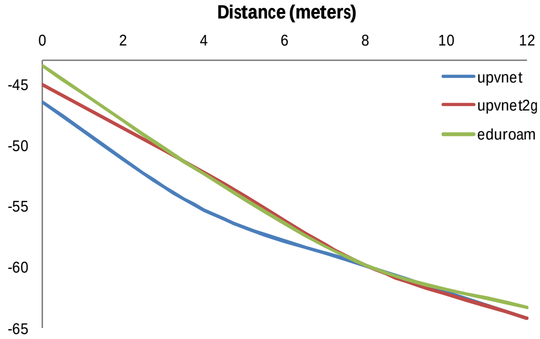

Figure 16. Signal strength on the second floor.

The analytical study is performed for three networks (UPVNET, UPVNET2G and EDUROAM). In order to draw each one of these graphs, we have estimated the average value of the three signals provided by each wireless network.

Fig. 17 shows the average value of the signal strength depending on the distance to the AP on the ground floor. Expression 1 shows the equation for the trend line (black line in Fig. 17) of our measurements. As we can see, it is a polynomial expression of fifth grade, with a correlation coefficient of $R^2=1$. However, we can appreciate a slight difference between them in positions close to 3-4 meters, and further away than 17 meters of the APs.

$$Y=-0.0001x^5+0.0066x^4-0.1078x^3+0.6889x^2-2.3012x-54.75 \qquad (1)$$

where Y represents the average value of the received signal strength in dBm and X is the distance in meters to the AP.

Fig. 18 shows the average signal strength provided by the APs located on the first floor, as a function of the distance to the APs. In positions further than 8 meters of the APs, both graphs vary very few between them, although the rest of the graph is identical. Equation 2 shows the expression for the trend line (black line in Fig. 18) of our measurements. The behavior of wireless signals based on the distance is described by a cubic polynomial with a correlation coefficient of $R^2=1$.

$$Y=-0.0117x^3+0.0665x^2-3.9909x-46.833 \qquad (2)$$

where Y is the signal level in dBm and X is the distance in meters to the AP.

In Fig. 19, provides the behavior of the signal level on the second floor. Equation 3 shows the trend line (black line in Fig. 19) of our measurements. In this case equation 3 is a 3rd degree polynomial with a correlation coefficient of $R^2=1$. It shows that both graphs have a nearly perfect match, as its correlation coefficient shows.

$$Y = 0.0021x^3 + 0.0292x^2 - 2.2229x - 45 \qquad (3)$$

where Y is the average signal value in dBm and X is the distance in meters to the AP.

VII. Conclusion

When the deployment of a wireless network on the inside a building is needed to offer complete coverage for all the users, we should pay particular attention to the correct placement of the AP. We have analyzed the behavior of the signal strengths of the APs located in the CRAI. The measurements provided have enabled us to represent the signal evolution depending on the distance to the AP.

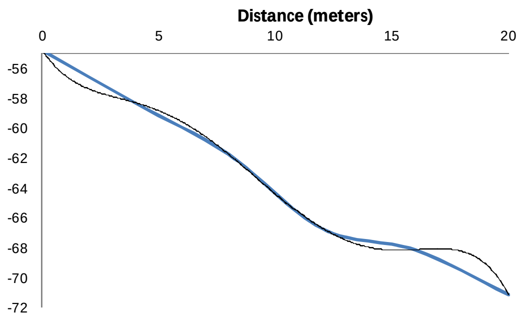

Figure 17. Average signal strength of the ground floor

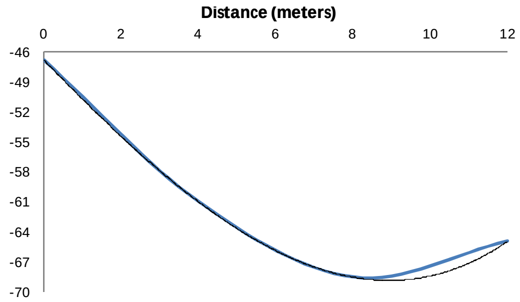

Figure 18. Average signal strength of the first floor.

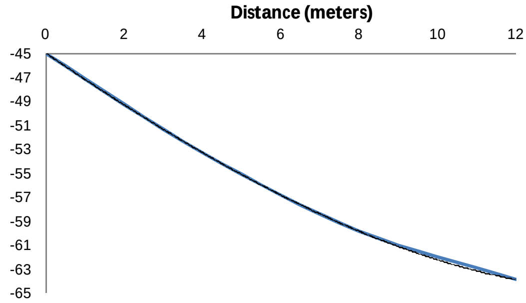

Figure 19. Average signal strength of the second floor

With these measurements of the coverage maps of each floor, have been drawn the pictures processed for this analysis have allowed us to determine the places where the signal is not good (less than -70 dBm), and so relocate APs and add more, if it was needed. With all of these, we have performed an analytical and comparative study, with the three networks. After this study, we can see that, the EDUROAM and UPVNET have very similar coverage, while UPVNET2G is a little bit better. This phenomenon is a strange because the same APs give the coverage for the 3 wireless networks. Moreover, we have detected that the worst designed floor was the ground floor (in terms of APs distribution). We propose the relocation of some of the existent APs and to add new APs to cover the shadow areas where the signal strength is below than levels appropriate for Internet access.

We have characterized mathematically, the behavior of the signal strength in each floor. In all cases, the behavior can be expressed by a polynomial expression of degree equal to or greater than 3, depending on each floor. The APs of the CRAI building give acceptable radio coverage levels up to 16 meters from the AP's position.

On the other hand, we have estimated the average value for all floors, depending on the distance to the APs and we see that it could be modeled as a fifth degree polynomial with a correlation coefficient of 1. It is shown in equation 4. The signal strength Y is given in dBm and X the distance to the AP, in meters.

$$Y=4\cdot 10^{-5}x^5-0.0024x^4+0.0455x^3-0.2065x^2-1.966x-50.792 \quad (4)$$

Finally, we have observed a trend in the signal behavior where it reduces its strength in a staggered manner (as we see clearly in Fig.14 and 17). In all other plants, this behavior is less visible. However, due to new tests that we are carrying out in other buildings, it seems that this pattern is repeated.

We are now working on the design to place more than one AP in the same location in order to provide higher bandwidths for the students. Moreover, we are proposing the use of APs in standby mode to provide fault tolerance. Finally, APs should be updated to IEEE 802.11n standard in order to achieve higher speeds and greater distances.

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