IEEE 802.11g Radio Coverage Study for Indoor Wireless Network Redesign

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***Abstract*— An efficient wireless design and development is essential to ensure a good performance of the WLANs. It supposes a good estimation of the number of APs, their locations according to the structure of the building, a good channel distribution and an adequate level of transmission power in order to avoid overlapping but providing the largest coverage. Otherwise, a WLAN may be composed by more access points, so it may be more expensive, but with a worse function due to the radio overlapping among APs in the same channel. In this paper, we show how a WLAN can be redesigned in order to improve its wireless coverage and function. It is based on studying the distribution and features of a public building in a Spanish University in order to determine the optimum access point location and to assign the appropriated channel. In this case, this WLAN allows users to connect to one of the available SSIDs in the target building. Results obtained from the proposed redesign have been very successful from the point of view of performance and coverage.**

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

I. INTRODUCTION

One of the most important aspects in the development and implementation of wireless networks is to ensure the optimal access to all network resources. Nowadays, ubiquitous connection to the network services is essential to let the workers and students perform their tasks. Wireless networks are widespread in both the enterprise and academia environments, providing support for wired networks and mobility to users. Wireless networks allow them to access all the services offered by the institution even when they are moving. Users can access to all resources in the infrastructure.

It is very important to know the behavior of signals within a building. An analytical analysis of the signals generated by the access points (APs) can help us to improve network coverage within the building [1]. In this new paper, we enhance our analytical study in order to propose a redesign of the wireless network of the Centre of resources for the research and learning (CRAI) of the Higher Polytechnic School of Gandia, a campus of the "Universitat Politecnica de Valencia" (UPV) in Spain. We propose a new distribution of the locations of APs with a new channel scheme. Moreover, we have included a study of wireless coverage in order to compare both values. In this comparison, we show that wireless signals in indoor environments have a different behavior, which could be used for other purposes.

One of the most important things which must be considered when a wireless network is being designed is the wireless signal losses. They depends on the number of walls and obstacles crossed in its propagation path, the materials used in the building construction, the type of obstacles, the multipath effect, and others electromagnetic waves from others systems which interference with the wireless signal. But, generally, only the fixed obstacles and walls are taken into account in the design process. There are several materials such as metal or wood very used in buildings or simply through normal walls and floors, which affect to wireless signals reducing significantly their signal level [1, 2]. In contrast, interferences caused by electromagnetic waves from other systems can be reduced selecting the most appropriate frequency band for the wireless network and a good channel assignment

When a wireless network is designed in a specific environment, it is necessary to study the distribution of the place in order to determine the better location for each AP and the channel distribution. The goal is to provide the greatest possible coverage but avoiding overlapping among channels according to the building distribution. Obviously, it is impossible to define only one model for all places and, sometimes, it is very difficult and tedious to analyze each place in detail before installing, because each one has a different distribution and with different sources of interferences. So, although it is quite easy to estimate the area of the radio coverage in a free space, it is very difficult to calculate it in indoors since the building distributions are not uniform [3]. Moreover, the irregular disposal of the objects makes the ray tracing, which mainly affects to the multipath loses, very difficult to be controlled. However, there are several features of the indoor environments which should be taken into account in order to reach a well-designed WLAN.

Moreover, an accurate design means a good sized network, that is, only APs/routers needed to cover the service area and to obtain high efficiency must be bought.

Moreover, performing a correct and optimal design of an indoor wireless networks would subsequently let the network administrators include multiple services such as positioning and tracking of people and objects [4]. So, the coverage study showed in this paper is applicable to other research fields such as wireless sensor networks [5] where the designing process presents similar inconvenient.

In addition to all the design parameters discussed above, it is essential to analyze and study which type of traffic and users the target WLAN goes to support, and how much and how many respectively. Depending on that, it will require more or less resources, bandwidth and performance. Finally, the physical distribution must be considered in order to select the APs locations since each AP needs a power supply and a point of connection to the wired network.

In short, the key issues to design and install a WLAN are to study the physical aspects of the area where the WLAN goes to be installed, to select the type of APs which fulfill the necessary requirements according to the users and traffic estimated, to perform a coverage study to assign the most appropriated location for each AP taking into account the physical features of the building (where obstacles, power supplies and points of connection to the wired network are located), and to do a good channel distribution to minimize interferences among APs.

In this paper, we use the analytical study of the building in order to know the wireless signal behavior in the CRAI building. These measures will allow us to develop new techniques for indoor network designs. In order to validate our measures, we will perform a new analysis within another scenario and compare the results between them. We will show the wireless network redesigned and how the new APs placement provides better wireless coverage.

The rest of this paper is structured as follows. Section 2 shows some related works with radio coverage and redesign of wireless networks. Section 3 presents the scenario and the tools used to perform our measurements. Section 4 explains the results of our study drawn in coverage maps. Section 5 makes a comparative study of the three analyzed radio signals in each floor. The analytical study is included in Section 6. Section 7 shows the redesign of the CRAI wireless network from the obtained measurements. This consists on relocating the wireless devices and reassigning channels according to the new distribution of devices. In order to check our proposal, we perform another analytical study in another building and show the comparison between the results in Section 8. Finally, Section 9 summarizes the conclusion and future works.

II. Related Works

Different aspects of the WLANs' coverage have been studied in several papers. There are both empirical [7] and analytical [8] studies. On the one hand, A.R. Sandeep et al. [7] suggest an indoor empirical propagation model (IEPM) in order to predict the signal strength of an indoor Wi-Fi network. It is a predictive model based on the Wall Effect Factor (Wef) and the Wall Attenuation Factor (Waf). From this model, authors can calculate the RF coverage area before installing a WLAN and so that calculating the number of access points needed. Therefore, this model means low cost and development time. On the other hand, Eisenbl et al. [8] perform an analytical study about the best location for APs and channel assignment in order to improve the performance of a WLAN. Up to now, these features have been analyzed independently, but according to this paper the greatest optimization is achieved from studying these two features simultaneously by mathematical programming. Authors propose an integrated model in order to reach a balance between both features and to optimize the indoor design of WLANs.

Expanding analyzing studies, M. Kamenetskyt et al. [9] analyze different methods for obtaining the most optimum location for the WLAN's access points. In order to evaluate the performance of these methods, they use an objective function which maximizes the coverage area and signal quality. Then different approaches to coverage planning for WLAN systems are reviewed and the most suitable for numerical evaluation are selected. From this evaluation, authors propose a new optimization scheme based on the combination of two approaches: using pruning in order to set initial locations for access points and refining these by using either neighborhood search or simulated annealing.

Then, E. Amaldi et al. [10] present a new modeling approach taking into account the effect of the IEEE802.11 access mechanism. It influences on radio coverage due to the coverage overlap between APs and its impact on the system capacity. So, they explain and discuss novel mathematical programming models based on quadratic and hyperbolic objective functions considering this. Finally, some initial results on synthetic instances are shown.

Some abovementioned authors improve its initial approach (published in [10]) because it is difficult to tackle even for small instances. So, they propose and analyze effective heuristics in [11] to tackle hyperbolic and quadratic formulations in order to maximize the overall network capacity. It is based on a combined greedy and local search algorithms turn out to provide near-optimal solutions in a reasonable amount of time.

Following with empirical papers, Kaemarungsi and Krishnamurthy [4] study the performance of the received signal strength (RSS) from IEEE 802.11b wireless network interface cards in order to improve the indoor location systems based on location fingerprints. Moreover, they point out the influence of the users' presence on the RSS, both the proximity of the human body to antenna and its orientation. These features affect the mean value and the spread of the average RSS values. So, if the position system is deployed in an environment with people, it is essential to take it into consideration while collecting RSS values for the fingerprint. In contrast, for applications that make use of sensors without human presence, this influence shouldn't be considered.

J. Lloret et al. [12, 13] show 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 quick successful results. 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 analytical 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. [14] present a comparison of the IEEE 802.11a/b/g/n variants in indoor environments in order to know which the best technology is. This comparison is made in terms of the RSS indicator, the coverage area and the measurements of interferences between channels. This study only provides data from a building. So, it is difficult to extract a generalization in the wireless signals behavior.

In [15], authors propose a new WLAN design strategy called capacity based WLAN design. The method guarantee radio coverage to the target service area and provide a specified data rate capacity to carry the traffic demand from each user in the service area. The methodology proposed determines the number of APs, frequency channels, power level and the placement of the APs that ensure the constraints as data rate density requirements, radio propagation conditions and physical limitations, related with receiver sensitivity. Authors performed several design experiments, which show the benefits of their method over the traditional coverage – based design.

Moreover, I. Broustis et al [16], suggest that when we perform large wireless sensor network deployments, it is possible to detect large amount of interference, because their small capacities. They tell us that to improve the overall capacity of the network; we can base our proposals in the intelligent frequency allocation across APs, in the load balancing of user affiliations across APs and in an adaptive power control for each AP. In their work, they search interdependencies between the three functions in order to understand when and how to apply them to the network design. The authors performed the measures following a study based on the quantification of the effects of three optimization schemes proposed in many different scenarios. From the results, we can see that applying simultaneously the three optimization schemes is not always preferable, because it can sometimes degrade the performance by up to 24% compared to using only two of the schemes.

III. Scenario description and used Tools

The CRAI building was built in 2007. It belongs to the Higher Polytechnic School of Gandia. It is composed of 3 floors where different services for the students are offered. It contains the library, computer labs and open access classrooms. Figure 1 shows the map of this space. It is the H building of this university campus.

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

A. The building

The ground floor (see Fig. 2) contains an information desk, several staff offices, a library and a large study room with a consultation area and several group study rooms. Finally, 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, some classrooms to perform Final Degree Projects, and others group and individual study rooms.

On second floor (see Fig. 4), there are a large library with magazines, journals, books and audiovisual resources, and some computer labs and professor offices.

B. Description of UPV Wireless Network

Higher Polytechnic School of Gandia is a campus of the UPV and shares four wireless networks with the main campus, their SSIDs are EDUROAM, UPVNET2G, UPVNET and UPV-INFO. Each one of these allows university users to access to the Internet and the university resources. Their main features are:

- UPVNET: a wireless network with direct connection to all the resources of the UPV. It requires a wireless card with configured with WPA/WPA2 security.
- UPVNET2G: a direct network connection to all resources of the UPV and the Internet. It requires a wireless card configured with WPA/WPA2 security.
- EDUROAM: this wireless network is widely deployed in universities and research centers in Europe. It provides Internet access for all their members. Users only need a username and a password from their home institution. It requires a wireless card configured with WPA/WPA2 security. This network only provides Internet access.
- UPV-INFO: this wireless network works as a consultation area. It only provides all information about how the wireless network cards must be configured in the users' devices in order to connect them to some of the abovementioned networks. It uses private IP addressing and it does not allow users to access to the Internet. A second connection is needed to access to the Internet and the UPV resources. This second connection can be a Virtual Private Networking (VPN). It should only be used by very old computers that do not support WPA encryption.

In this paper we are going to analyze three of these networks (UPVNET, UPVNET2G, EDUROAM), because these are the only ones that allow users to access to the Internet.

Figure 1. Map of Polytechnic high school of Gandia.

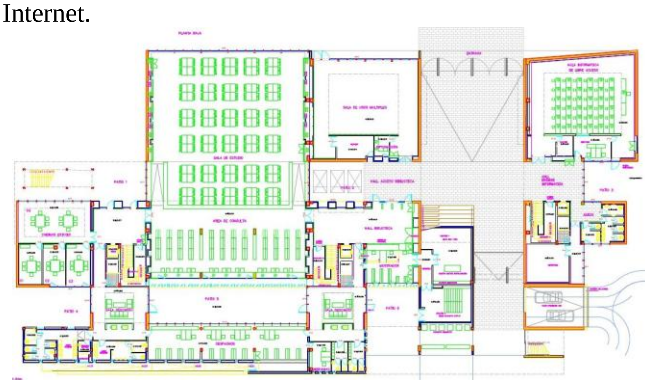

Figure 2. Ground floor of the CRAI bulilding.

Figure 3. First floor of the CRAI building

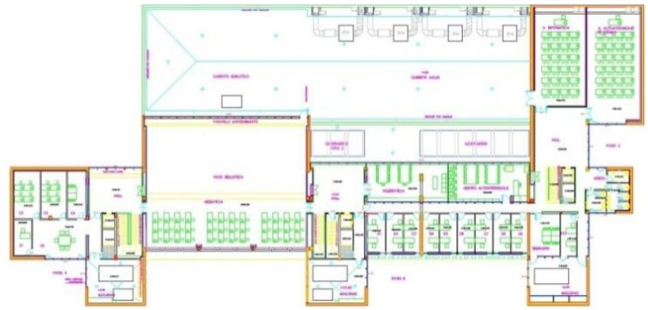

Figure 4. Second floor of the CRAI building

C. Software and hardware used

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 these measurements:

- Linksys WUSB600N [17]: it is a USB wireless device used to gather measurements. It can capture signals from the IEEE 802.11 a/b/g/n standards. Its power transmission is 16 dBm for all standards and the receiver sensitivity is about -91dBm in both internal antennas. Transmission power consumption is less than 480mA and it consumes 300mA in the reception mode.
- Laptop: it was used to take coverage measurements. It has a dual core processor with 2 GHz per core and 2 Gbyte of RAM Memory. Its operating system is Windows Vista.
- Cisco Aironet 1130AG (AIR-AP1131AG-E-K9) [18]: this AP is the model 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 from 100m to 122m in indoors (as a function of the IEEE 802.11a or IEEE 802.11g variant). The maximum distance for outdoor environments is about 198 m and 274 m. It can be powered by PoE (Power over Ethernet).

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

- InSSIDer [19]: it is a free software tool which detects and controls the wireless networks and the signal strength by a graphical way. This program lists all detected wireless networks and provides several details about them such as their SSIDs, MAC addresses, channels, the radio signal strength indicator (RSSI), network type, security, speed and signal intensities which allow to control the signal qualities.

IV. COVERAGE RESULTS

We only have considered the walking area from which users typically connect to the wireless network. So, bathrooms, exterior stairways, storage rooms, etc. have been excluded. In order to perform this coverage analysis, a grid of 4 meters x 4 meters has been drawn in each floor. This allows us to take measurements for the different networks from the same places. The laptop in charge of taking measurements was located at a height of 100 cm above the ground.

A. Ground floor

This subsection shows the coverage study on the ground floor.

There are 5 APs to 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 fig. 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 on the ground floor. Room A presents signal strength of -90 dBm due to the signal attenuation suffered by the wireless signals when they cross some walls.

Fig. 6 shows the coverage area for the UPVNET2G wireless network on the ground floor. We find three places where signal strengths are higher than -50 dBm. These places are just those ones where the APs are located currently. The multipurpose room has a very low coverage on the left side because the signal is greatly attenuated by several walls.

Fig. 7 shows the value of signal strength for EDUROAM wireless network on the ground floor. Again, there are three places with signal strengths higher than -50 dBm, which correspond to the current location of the 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 strengths measured on the first floor. In this case there are 4 APs to cover the entire plant. There are 4 places with the highest signal strengths (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 important signal attenuation.

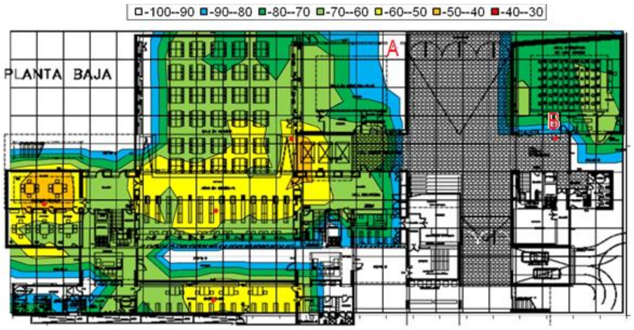

Figure 5. Radio coverage map of the ground floor for UPVNET

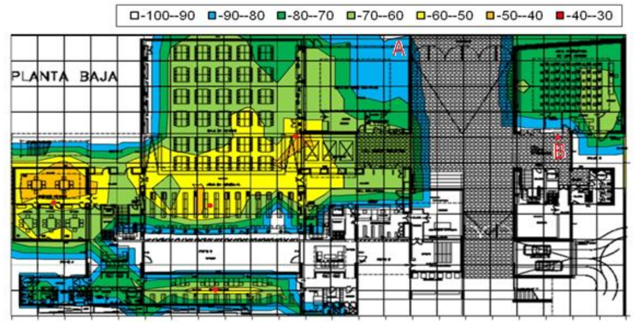

Figure 6. Radio coverage map of the ground floor for UPVNET2G

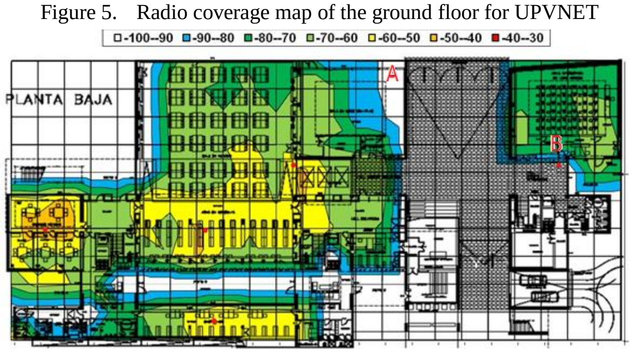

Figure 7. Radio coverage map of the ground floor for EDUROAM

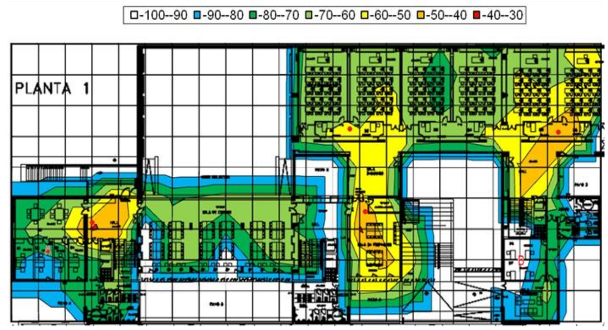

Figure 8. Radio coverage map of the first floor for UPVNET.

Fig. 9 shows the UPVNET2G wireless network signal strengths on the first floor. We can see that the classroom on the left side is not well covered because of the position of the AP. It is located on the right side 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 strengths 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 low signal strength (lower than -90 dBm).

C. *Second floor.*

This subsection shows the signal strengths measured on the second floor. The floor is covered by 4 APs.

Fig. 11 shows the signal strengths for UPVNET wireless network on the second floor. The highest signal level is provided by the AP located at the professors offices zone (central zone of the image),which provides signal levels lower than -60 dBm. Moreover, the AP located in the hall of the two computer rooms (top right of the Fig. 11), covers virtually the entire rooms, registering levels of -70dBm in the teacher's desk. The APs located at the central-left and the bottom-left areas of the library, have signal levels around -60dBm, except at the areas near to the outer walls where values of-70dBm have been registered.

Fig. 12 shows the signal strengths from the UPVNET2G network on the second floor. In this case, the signal is propagated with levels above -60dBm, practically in both computer rooms (top right of the image). In contrast, the professor offices (central zone of the image) register levels close to -50dBm. Finally, the area of journals and audiovisual resources of the library (bottom - left of the image) presents levels around -60dBm, showing levels around to -50dBm in the area near to the AP.

Fig. 13 shows the signal strengths from EDUROAM wireless network on the second floor. The signal strength offered by the EDUROAM network is slightly lower than those ones shown for UPVNET and UPVNET2G networks. We can see that there are more areas with signal levels close to -70dBm. This happens in the computer rooms (top right of the image) and in the library (bottom - left of the image). Most of these areas are zones near to walls or walkways, which are not usually used as workplaces.

We can conclude that the signal is correctly broadcasted through the entire floor and their signal strength levels are enough acceptable to cover the working places.

After analyzing all the radio coverage images, it is easy to see that the behavior of the wireless signal in each floor is quite similar, only small variations have been registered. In addition to this, we have checked that the received signal strength is very low from bathrooms and toilets. This is because the amount of water pipes and copper tubes in the walls affects to the propagation path of the wireless signals attenuating them. We have also found low signal strength levels in the stairwells. The stairs usually are made of metal framework and a foundation which avoids a correct propagation of the signal.

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

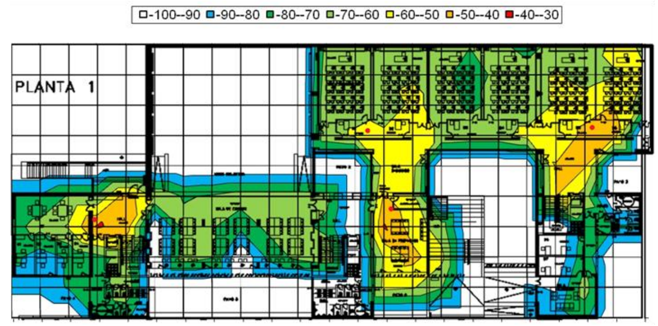

Figure 10. Radio coverage map of the first floor for EDUROAM

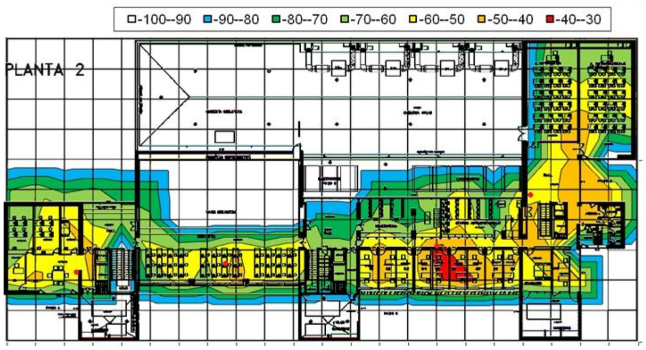

Figure 11. Radio coverage map of the second floor for UPVNET

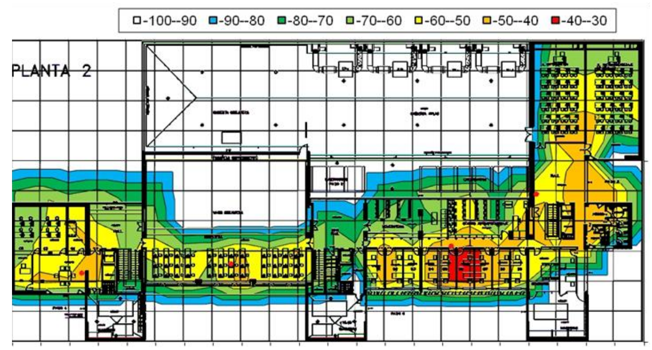

Figure 12. Radio coverage map of the second floor for UPVNET2G

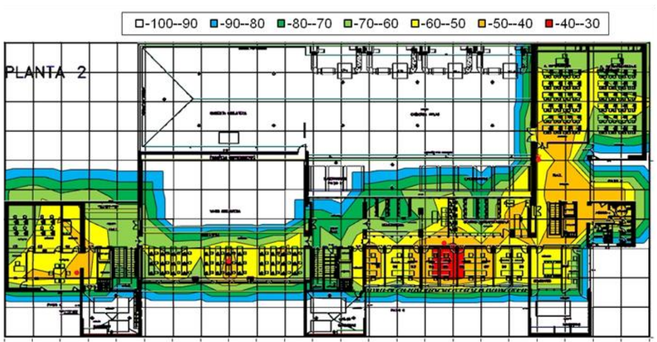

Figure 13. Signal strength on the ground floor.

V. COMPARATIVE STUDY

In this section we compare the three received wireless signals from each available wireless network on the same plant. Fig. 14 shows the three signals at 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 which reaches the highest signal strength. UPVNET and EDUROAM show similar behaviors although there are some locations where the received signal from EDUROAM network is better.

Fig. 16 shows the behavior of signal strength on the second floor. UPVNET2G and EDUROAM show the same behavior from 3 meters to around 10 meters, but from 0 to 3 meters and from 10 meters to 12 meters, the signal strength from EDUROAM network is better. The lowest signal strength is always performed by UPVNET network. Keeping in mind all graphs, it is easy to conclude that according to signal strength, the best wireless network is UPVNET2G. Furthermore, we observe that the ground floor presents generally better signal strengths than in the other two floors.

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 from the AP. In the previous section, we have shown the signal strength per floor and per SSID (Figs. 14, 15 and 16). In this section, we are going to work with the average value of all APs (per floor) and the mean value recorded for the three signals in order to analyze and generalize the overall network behavior since all APs used in the network are equal and the three signals are provided by the same AP. The mathematical equation is calculated from the tendency line of each graph.

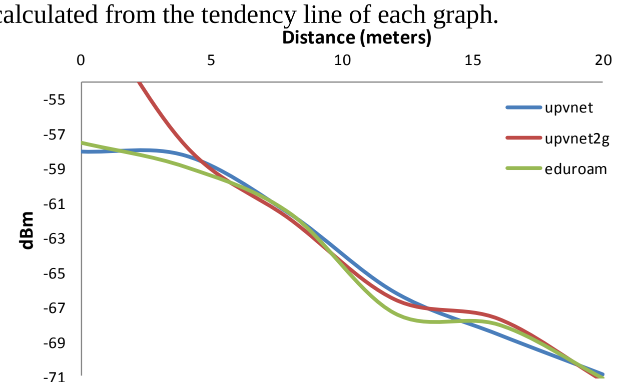

Figure 14. Signal strength on the first floor.

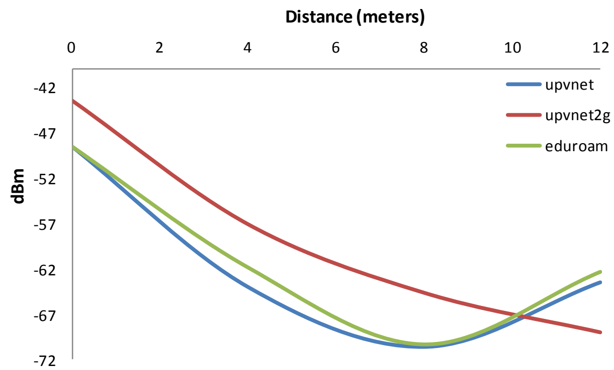

Figure 15. Signal strength on the second floor.

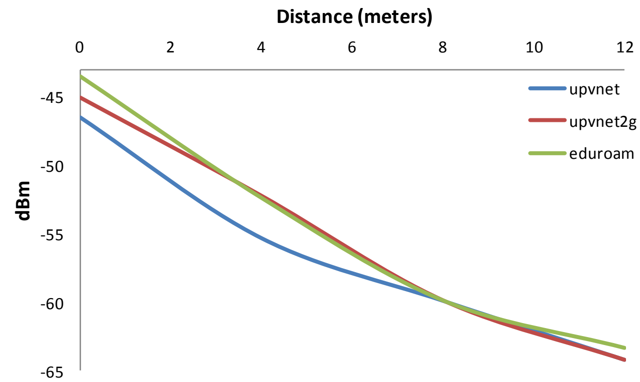

Figure 16. Radio coverage map of the second floor for EDUROAM

The analytical study is performed for three networks (UPVNET, UPVNET2G and EDUROAM) again. 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 from the AP on the ground floor. Expression 1 shows the equation for the trend line (black line in Fig. 17) from our measurements. As we can see, it is a fifth-order polynomial equation, with a correlation coefficient (R^2) equal to 1. However, we can appreciate a slight difference between them in positions close to 3-4 meters, and further away than 17 meters from the APs.

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

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

Fig. 18 shows the average signal strength provided by the APs located on the first floor as a function of the distance from the APs. In positions further than 8 meters from 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) from our measurements.

The behavior of wireless signals based on the distance is described by a cubic polynomial with a correlation coefficient (R^2) equal to 1.

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

Where Y is the signal level in dBm and X is the distance in meters from the AP.

Fig. 19 provides the behavior of the signal strength on the second floor. Equation 3 shows the trend line (black line in fig. 19) from our measurements. In this case equation 3 is a third-order polynomial equation with a correlation coefficient (R^2) equal to 1. As its correlation coefficient shows, both graphs have a nearly perfect match,.

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

Where Y is the average signal value in dBm and X is the distance in meters from the AP.

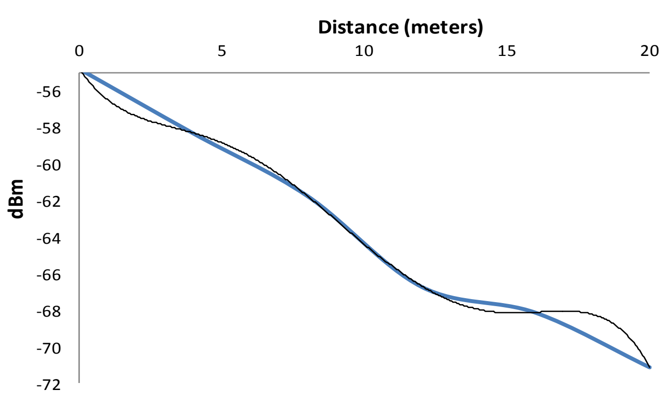

Figure 17. Average signal strength on the ground floor

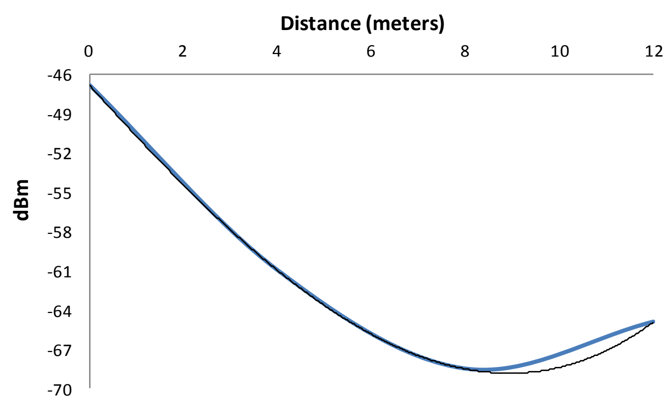

Figure 18. Average signal strength on the first floor

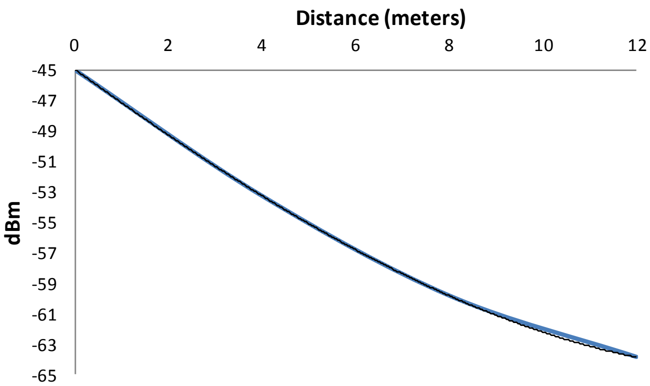

Figure 19. Average signal strength on the second floor

VII. WLAN Redesign

Designing WLANs which main focus is to provide the best service using the available resources efficiently requires careful planning. WLANs can be as small as a home network or as large as a network of a company with complex distributions and several buildings. Before installing a WLAN, it is essential to have the technical information about network devices and a well-defined plan for the development process. The usual sequence of steps in the APs location process is as follows:

1) Firstly, an AP is placed in each corner of each floor of the building, and it is measured the maximum coverage area for each one of them.

2) From these measurements, it is easy to determine the most suitable place for the APs taking into account that it is only needed 15% of overlapping area.

This is the most reliable process in order to find out the best location for the APs. However, it is very tedious, impractical and it implies too much time for the networks designers. Moreover, sometimes it is unfeasible for example in big buildings due to the number of measurements needed to make an accurate decision about the best potential locations or in buildings where it is not possible to gain access to take measurements [20].

We are going to relocate APs and redesign a WLAN already installed, because as we have seen in Section 4, there are some areas where wireless coverage is very poor with wireless signal strength lower than -70dbm. So, in this section we propose several changes to improve the network infrastructure and to guarantee the greatest coverage in such areas. Moreover, wireless channels used by APs are also redefined in order to reduce the interference between them.

A. WLAN Planification

In order to relocate the APs, we have taken into account the structure and distribution of the building. This is so, because there are some manufacturing materials which attenuate wireless signals significantly, for instance metal or wood. So, there are environments such as bathrooms or large fitted wardrobes where APs must not be close to.

According to the results and coverage maps shown in section 4, we decided to resign our network in order to improve its performance. The new APs placement is shown in fig. 20. Thus, several APs have been relocated on the ground floor. Firstly, the AP placed in the study room (point 1) is moved to the window and a new AP is added just in the opposite wall (point 2). This relocation has involved a better service for students who connect to the Internet in the study room because wireless coverage has been increased. Secondly, the AP located at the hall of the free access computer room is moved to beside wall in the same room. Its current position provided very low signal strength to this room. The estimated signal strengths in the ground floor are shown in fig. 21.

Moreover, on the first floor an AP (point 1) has been also relocated and two new APs have been added. The AP located in the hall on the left side (point 1) is moved to the door of the bookable study rooms. In this way, wireless signals pass through fewer walls and consequently they suffer less attenuation. The AP in point 2 is added in the center of the study room. This is a room where many students often go to work with their computers. As we have seen in the coverage maps on the first floor (section 4), some areas of the computer rooms do not have enough signal level, so we decided to add another AP in point 3 in order to improve the coverage. Fig. 22 shows the new APs location. The estimated signal strengths in the first floor are shown in Fig. 23. In both cases where APs have been relocated, we can observe that the signal strengths have been improved.

In contrast, we have not changed anything on the second place since we have checked that the signal strengths are good enough. Fig. 24 shows the position of the APs on the second floor.

Figure 20. Relocation of APs on the ground floor

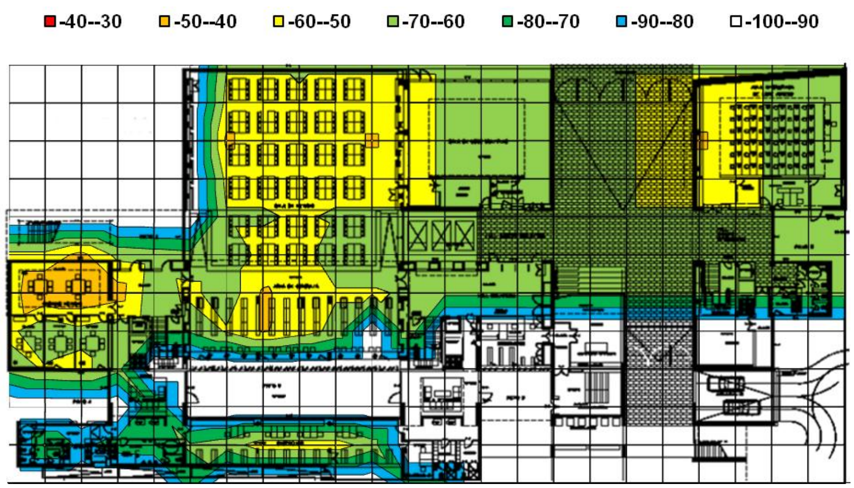

Figure 21. Estimated signal strength on the ground floor for the proposed AP relocation.

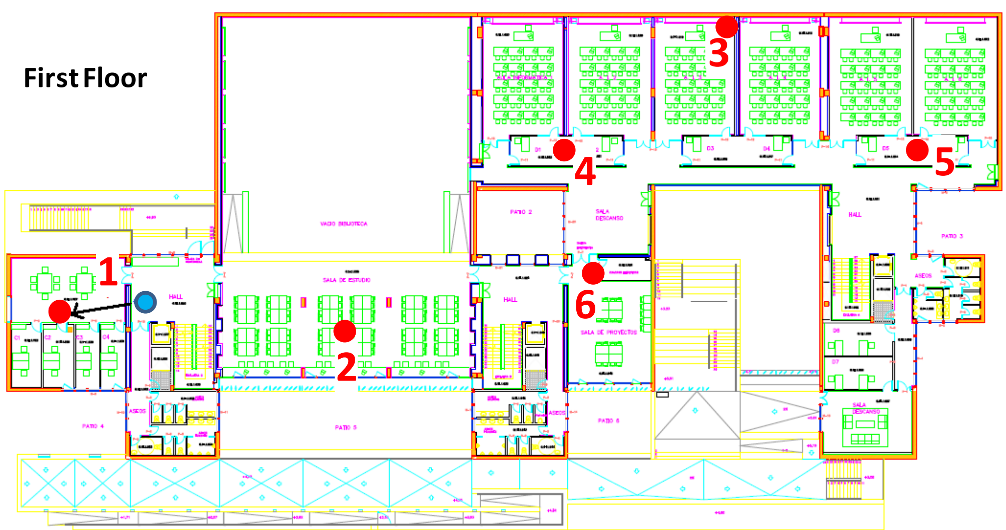

Figure 22. Relocation of APs on the first floor

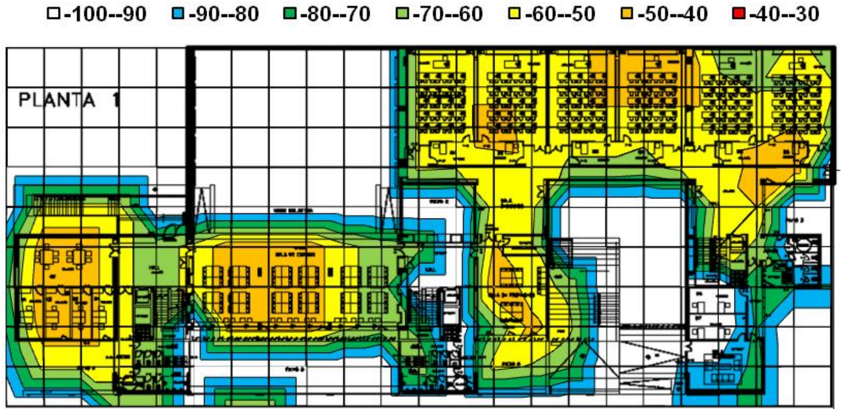

Figure 23. Estimated signal strength on the first floor for the proposed AP relocation.

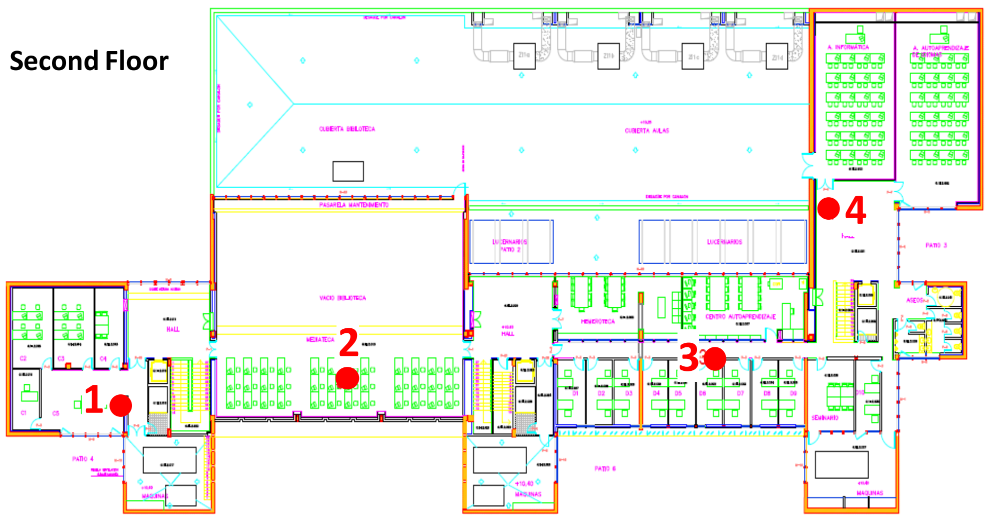

Figure 24. Relocation of APs on the second floor

B. *Channel assignment*

IEEE 802.11b and IEEE 802.11g standards define up to 14 channels available for wireless devices. But each country or geographic area applies their own restrictions regarding to the number of available channels. The channels are not completely independent because each channel overlaps and causes interference to the nearest four channels. Signal bandwidth (22MHz) is greater than the distance between consecutive channels (5MHz). For this reason, a gap of at least 5 channels is needed to avoid interference between adjacent cells. Using a gap of 5 channels means reaching a difference of 25MHz. Channels 1, 6 and 11 are usually the most used but the use of channels 1, 5, 9 and 13 in European domains is not bad for the performance of networks [2].

Fig. 25 shows the channel distribution from 2.412 to 2.484 GHz for the 5 main regulatory domains. In our case we use the regulatory domain of Europe, Middle East and Africa (EMEA) [13].

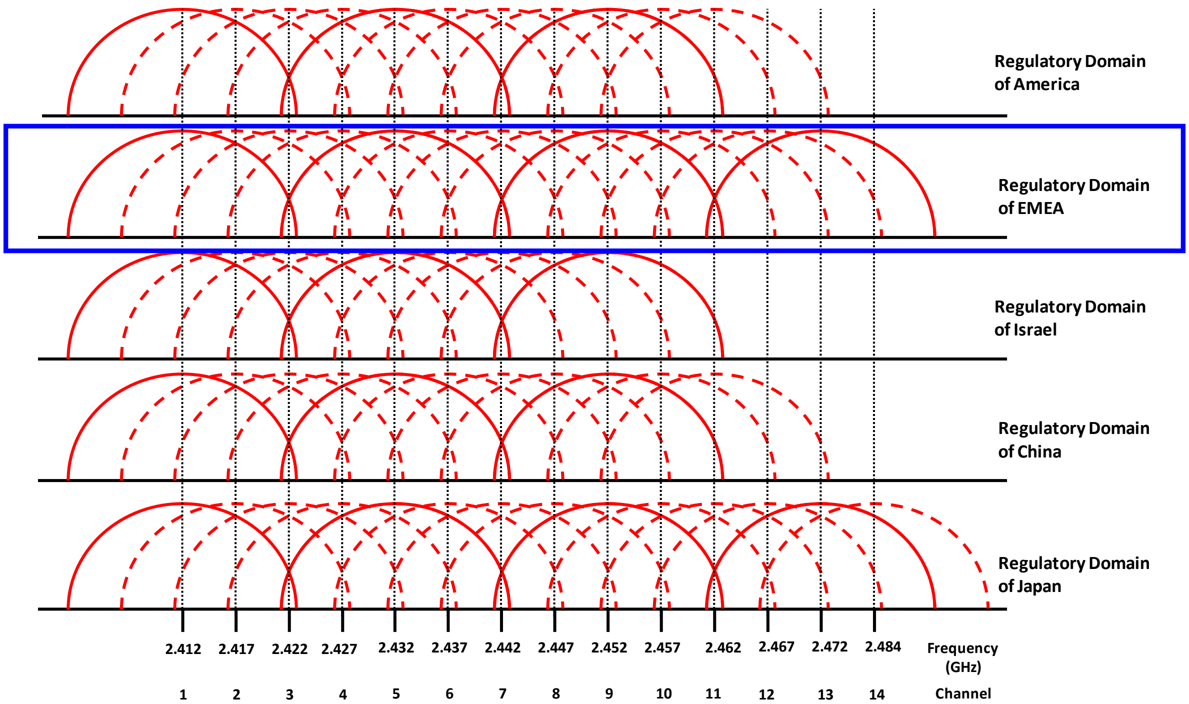

Figure 25. Channels in the frequency band of 2.4 GHz

TABLE I. CHANNEL DISTRIBUTION FOR THE GROUND FLOOR

Access Point	Channel distribution for ground floor	
	Proposed Channel	*Current Channel*
1	1	11
2	5	AP nonexistent
3	13	11
4	9	1
5	13	1
6	1	5

TABLE II. CHANNEL DISTRIBUTION FOR THE FIRST FLOOR

Access Point	Channel distribution for the ground floor	
	Proposed Channel	*Current Channel*
1	5	5
2	1	AP nonexistent
3	5	AP nonexistent
4	9	5
5	1	8
6	13	5

TABLE III. CHANNEL DISTRIBUTION FOR THE SECOND FLOOR

Access Point	Channel distribution for the ground floor	
	Proposed Channel	*Current Channel*
1	1	5
2	5	1
3	6	7
4	13	1

When new APs have been added to the network, we should define a new channel assignment for the network in order to avoid interference between the already installed APs and the new ones.

Thus, our proposal of channel assignment according to our relocation and considering one more AP for the ground floor is shown in table 1. Moreover, it can be compared with the current distribution channel in which the APs 1 and 3 share the same channel (channel 11) and the same happens with APs 4 and 5 in channel 1. This can make that these devices are interfering to each other. In our proposed channel assignment, these interferences will not occur.

In the same way, table 2 shows the channel assignment for the first floor before and after relocating the APs and adding two more. We can see that the APs 1, 4 and 6, was initially working on channel 5, while in our proposed channel assignment the interferences between devices are insignificant.

Finally, table 3 shows the channel assignment for the second floor where no change was needed. In this case, we change the channel allocation, only to not interfere with the devices of the lower floor.

As three tables show, the current channel assignment is made so that the devices do not interfere with the devices of the same floor. However, with the proposed channel scheme in this paper, interferences between floors are also avoided.

VIII. CURRENT PERFORMANCE OF THE WIRELESS NETWORK.

In order to measure the performance of the redesigned wireless networks in this study, we monitor the performance of them during the month of November 2012, both the 2.4 GHz band and the 5GHz band. As we can see in the graphs shown in Figures 26-35, the amount of traffic carried on each band is vastly different, nearly all traffic is managed in the 2.4 GHz band, although the traffic in the 5GHz band is significant too. Moreover, we can also see how the traffic is greatly reduced during weekends.

In figure 26, we can see the evolution of the amount of input bytes in both bands and the output bytes in figure 27. Figure 28 shows the total amount of transmitted fragments by the wireless networks. Then, the figures 29 and 30 show the evolution of the amount of frames CTS (clear to send) which are received and which are not received respectively in response to an RTS (Request to Send). It should be pointed that this evolution in the 5 GHz band is nearly null. Moreover, figure 31 shows the amount of transmission's retries and figure 32 presents the amount of transmission's multiple retries. Then, figure 33 show the evolution of the number of frames with some error in the FCS (frame check sequence) and figure 34 the evolution of failed frames in general. Finally, the last one (fig. 35) show the evolution of the number of ACK which are not received when expected. We represent the evolution of these frames to show the performance of the wireless networks for each available frequency band.

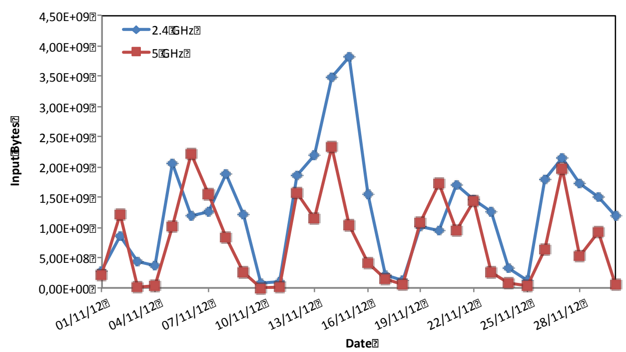

Figure 26. Input Bytes during November 2012

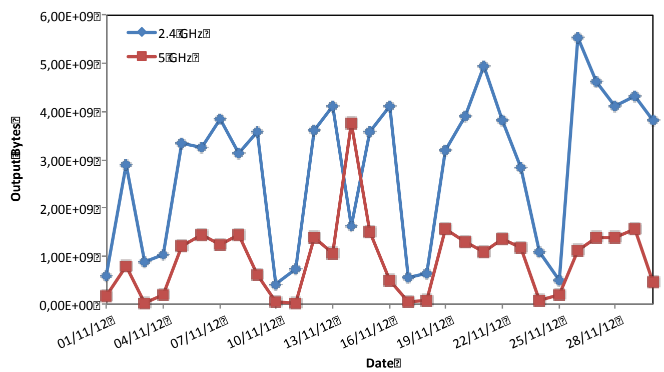

Figure 27. Output Bytes during November 2012

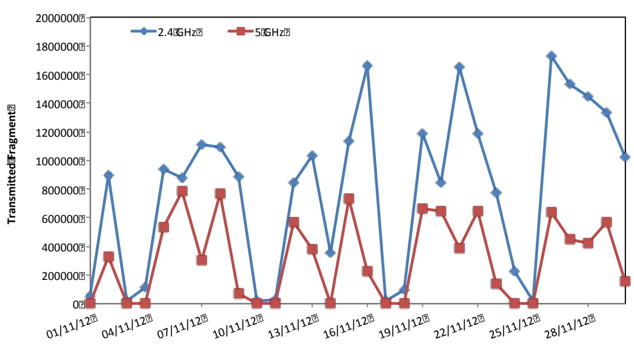

Figure 28. Transmitted Fragment during November 2012

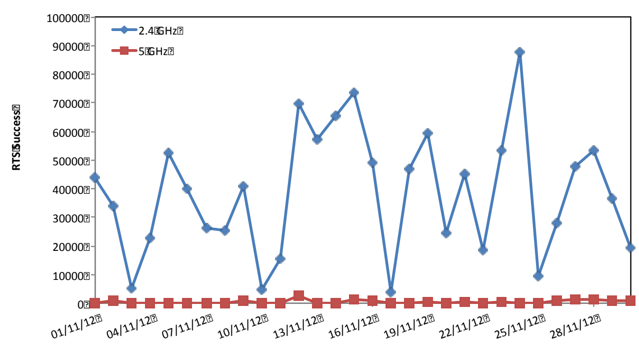

Figure 29. RTS Success during November 2012

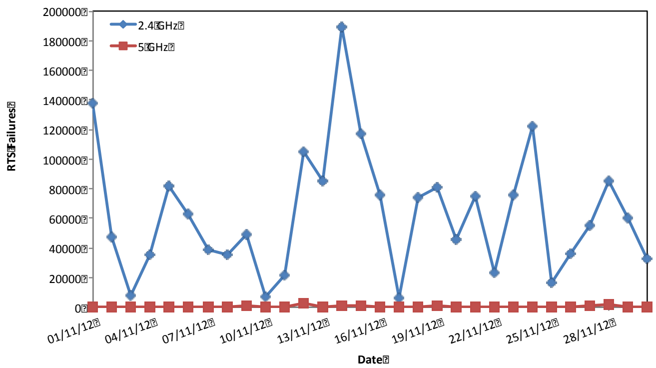

Figure 30. RTS Failures during November 2012

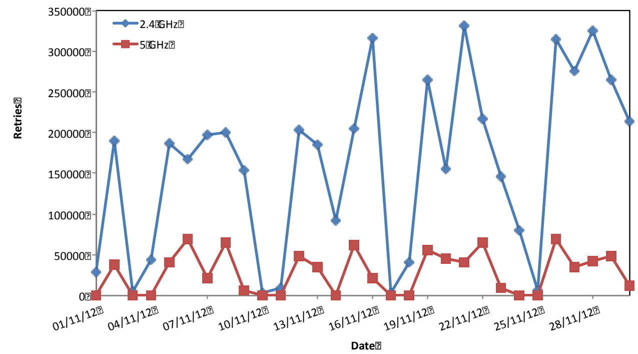

Figure 31. Retries during November 2012

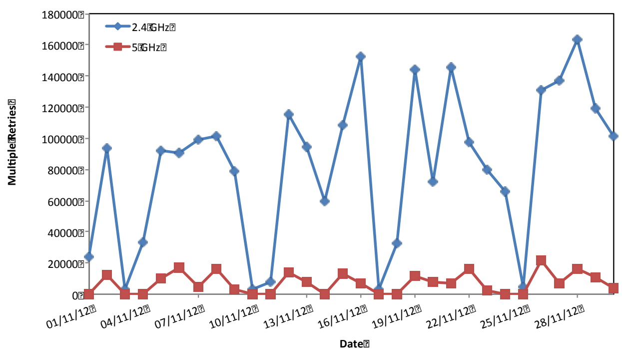

Figure 32. Multiple Retries during November 2012

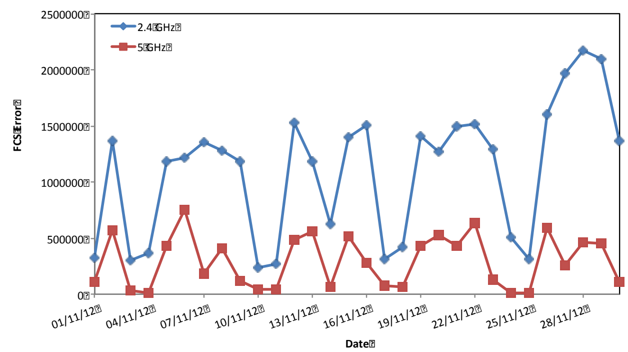

Figure 33. FCS Error during November 2012

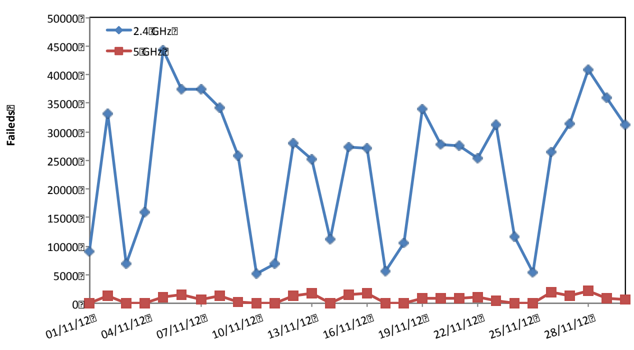

Figure 34. Failed during November 2012

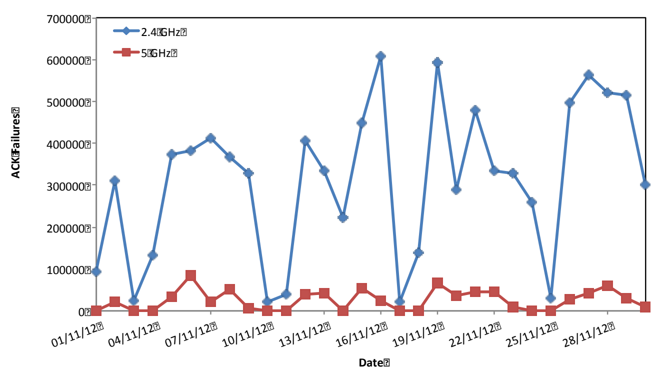

Figure 35. ACK Failures during November 2012

IX. COMPARISON WITH OTHER INDOOR COVERAGE STUDY

In order to check our study, the same process was performed in another building. In this case, only one AP was located within the building and signal strengths were measured from it. In this section, we see a comparison between both studies.

For these tests, we have considered a wide indoor environment of 91 m^2, with a length of 12.5 m., a width of 6.68 m. and a height of 2.30 m. This building is made of walls with different thickness and materials, as we can find in common houses. The plant has a rectangular base divided into two parts by a wall of 9 cm: the garage on the left side and the kitchen on the right side. The enclosure of the staircase is made of bricks with high consistency. All walls have a layer of plaster and paint on both sides. The bathroom is made of hollow bricks of 9 cm. These walls are covered by ceramic tiles. All external walls are double with a thermic and acoustic insulation of polystyrene of 5cm.

Fig. 36 shows the level of coverage obtained in IEEE 802.11g. In this case, we can see that the stairwell acts as a waveguide and signals are propagated easier in this direction than through the walls of the sides [21]. In this study, we conducted a study similar to that presented above. From that initial study, several conclusions were drawn regarding the signal behavior. However, we did not have other studies and it was difficult to generalize this behavior.

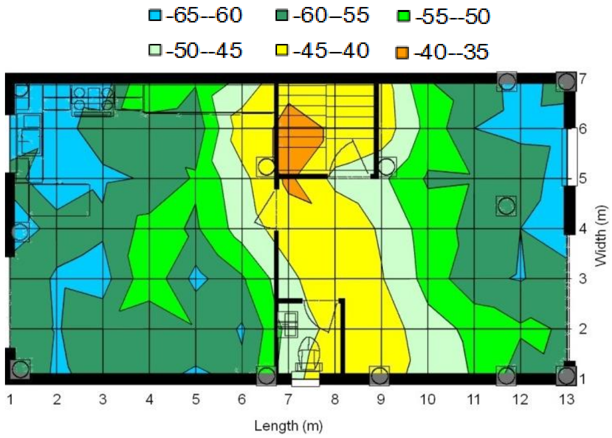

Figure 36. Coverage for the IEEE 802.11g

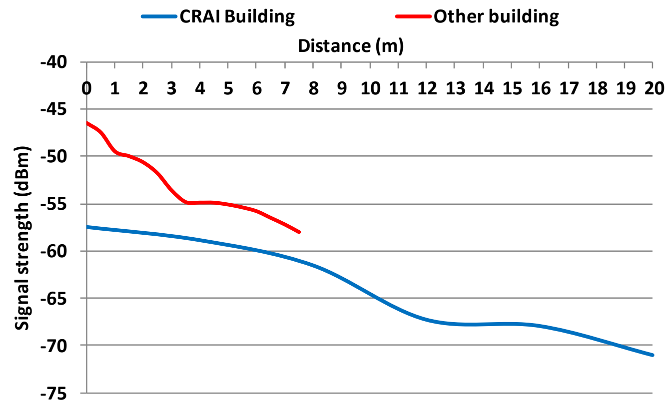

Figure 37. Signal strength for the IEEE 802.11g

For our comparison, we should observe the signal propagation through the walls, as it can be found in any building.

In this case, we can approximate the behavior of the signal by a sixth-order polynomial equation (see Eq. 4) with a correlation coefficient R^2 higher than 0.9999.

$$Y = -0{,}0356x^6 + 0{,}7695x^5 - 6{,}5329x^4 + 27{,}428x^3 - 57{,}836x^2 + 49{,}863x - 54{,}183 \quad (4)$$

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

The coverage maps shown in section 4 allowed us to analyze and characterize the behavior of the signals within this building. We performed an estimation of the average signal strength provided by the access points depending on the distance (considering the three floors). Equation 5 shows the behavior of signals when they pass through walls:

$$Y = 4 \cdot 10^{-5} \cdot x^5 - 0{,}0024x^4 + 0{,}0455x^3 - 0{,}2065x^2 - 1{,}966x - 50{,}792 \quad (5)$$

where Y represents the signal strength in dBm and X, the distance from the AP in meters.

Fig. 37 shows the behavior of the wireless signal working in IEEE 802.11g as a function of the distance. The red line shows the average of the signal strength in the new scenario and the blue line shows the average of the signal strength in the CRAI building. The most important conclusion is that the behavior of the signal is similar in both cases. However the signal strength values are different in both cases. This fact might suggest that the building area can influence in the coverage that an AP might offer. It is also shown that there are two flat zones that maintain the signal level in both signals and they could be used for future applications. We think that this difference is given by the multipath effect. In the CRAI building the signal levels (through walls) are acceptable in ranges up to 18 meters (having around -70dBm). If we extend the graph of the results obtained for the new scenario presented in this section, we estimate that we can achieve signal strengths higher than -70dBm up to 13-14 m.

X. CONCLUSION

The process to design a WLAN indoors could be a complicated and long process. It could happen that once the entire process has been performed, the result is not as successful as expected. Most probably some areas of low signal level may be created, where users do not have access to the network and to its resources.

In this work, we have performed an analytical analysis based on the signal strengths in order to enhance the performance of the WLAN of the CRAI building. We have analyzed the 3 floors inside the building and, as we have seen in section 4, some areas had low signal strength. So, from the coverage maps and using an analytical study, we redesigned the wireless network, establishing new locations for the APs and a reassignment of channels. Thus, we have improved considerably the wireless coverage for accessing to the network.

Therefore, this study can help to redesign wireless networks in similar buildings avoiding long and laborious processes. Moreover, the most suitable location for APs reduces the number of devices required to cover the whole building.

Nowadays, we are working with these measurements to propose a new indoor positioning system for wireless sensors which will allow us to monitor an environment more efficiently. Moreover we will add algorithms that mix the received signal strength indicator (RSSI) and the link quality indicator (LQI) in order to estimate the position inside the buildings [22]. We also want to expand this study for the IEEE 802.11n standard in order to reach higher data rates and greater distances.

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