UNIVERSIDAD DE EXTREMADURA

Escuela Politécnica

Máster en Ingeniería de Telecomunicación

Trabajo Fin de Máster

Estudio y análisis de la señal radioeléctrica del espectro WIFI en la Universidad de Extremadura

Alfonso José Sánchez Peco

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ÍNDICE

1. INTRODUCCIÓN

1. INTRODUCTION

1. 1. Abstract

This project aims to develop a study for the measurement of the electromagnetic signal in the radio spectrum of 2,4 GHz and 5 GHz, by taking into consideration all the networking of wireless access points belonging to Extremadura University in the campus of Cáceres, that are part of the Eduroam Network. In order to achieve this, mobile WIFI devices as well as data capture software have been employed.

Consequently, coverage maps, noise maps and other networks that do not belong to Eduroam will be generated and the results will be presented by means of heat maps.

Keywords: signal, University of Extremadura, Eduroam Network, coverage maps, heat maps.

1. 2. Objectives

- To analyse Eduroam Network´s properties in the University of Extremadura.
- To improve the services by changing the location of access points and to adjust the power issued from the signal.
- To detect shadow areas.
- To identify interference problems or non-authorized devices.

Resumen

Este proyecto tiene como objeto realizar un estudio de campo para la toma de medidas de la señal radioeléctrica en el espectro de 2,4 y 5 GHz, de toda la red de puntos de acceso inalámbricos en el Campus de Cáceres, de la Universidad de Extremadura pertenecientes a la red Eduroam, mediante la utilización de dispositivos WIFI móvil y un software de captura de datos. Se elaborarán mapas de cobertura, de interferencias y de puntos no pertenecientes a la red Eduroam. La información se presentará mediante mapas de calor en formato accesible vía web.

Palabras clave: señal, Universidad de Extremadura, red Eduroam, mapas de cobertura, mapas de calor.

Objetivos

- Analizar el funcionamiento de la red inalámbrica Eduroam en la Universidad de Extremadura.
- Mejorar el servicio mediante el replanteo de puntos y ajuste de la potencia de la señal emitida.
- Detectar zonas de sombra.
- Identificar problemas de interferencia o dispositivos no autorizados.

2. INTRODUCCIÓN TEÓRICA.

2.1. Redes Inalámbricas

A lo largo de los últimos años han surgido y se han hecho con gran popularidad nuevas tecnologías inalámbricas como WiFi, WIMAX, GSM, Bluetooth, Infrarrojos, etc, siendo los dispositivos inalámbricos una de las grandes revoluciones tecnológicas de los últimos tiempos.

Las tecnologías inalámbricas, o wireless, han conseguido esa popularidad gracias a la movilidad que permiten, llegando a cambiar la estructura y topología de las redes empresariales. Los dispositivos de almacenamiento de información que antes eran fijos ahora pueden ser portados y cambiar su conexión a distintas redes de una manera sencilla.

Es probable que en un futuro cercano todos los dispositivos que hoy utilizamos se unifiquen, pudiendo pasar a llamarse “Terminales Internet”, en los que se reunirían funciones de teléfono, agenda, reproductor multimedia, ordenador personal, etc.

Cada una de las tecnologías inalámbricas indicadas en el comienzo de este apartado tiene su ámbito de aplicación, sus ventajas y debilidades. A pesar de que nos centraremos en el estudio de las Redes Wi-Fi es conveniente conocer los distintos tipos de redes inalámbricas existentes en el cual se incluye la tecnología Wi-Fi. A continuación se muestra la clasificación de cada tipo de redes wireless.

2.1.1. Redes Inalámbricas Personales

Dentro de estas redes podemos integrar a dos principales actores:

- **Infrarrojos.** Estas redes son muy limitadas dado su corto alcance, su necesidad de visión sin obstáculos entre los dispositivos que se comunican y su baja velocidad (hasta 115 Kbps). Se utilizan principalmente en ordenadores portátiles, PDAs, teléfonos móviles e impresoras.
- **Bluetooth.** Es el estándar de comunicación entre pequeños dispositivos de uso personal, como PDAs o teléfonos móviles. Funciona en la banda de 2.4 GHz que no requiere licencia y tiene un alcance de entre 10 y 100 metros, según el dispositivo.

2.1.2. Redes Inalámbricas de Consumo

También distinguimos dos tipos:

- **Redes CDMA y GSM.** Son los estándares de telefonía móvil americano y europeo y asiático respectivamente.
- **WIMAX.** Es una tecnología wireless que ha sido concebida y desarrollada para suministrar servicios de Banda Ancha en tramos de pocos kilómetros, como campus universitarios, urbanizaciones, etc. El rango típico de WIMAX es de 3 a 10 kilómetros, aunque puede alcanzar más de 40.

2.1.3. Redes Inalámbricas de Área Local

Las WLAN, Redes Inalámbricas de Área Local, o Redes Wi-Fi serán el tipo de redes en el que se basa el presente proyecto, por lo tanto, a continuación se describirán detalladamente sus características, los elementos que las componen y su seguridad.

2.2. Tecnología Wi-Fi

Wi-Fi, es un conjunto de estándares para redes inalámbricas de área local (WLAN) basado en las especificaciones IEEE 802.11.

Fue creada por la Wi-Fi Alliance (anteriormente WECA, Wireless Ethernet Compability Alliance), la organización comercial que prueba y certifica que los equipos cumplen los estándares 802.11.

Se identifica con un símbolo con el estilo del ying-yang y su nombre no es un acrónimo de Wireless Fidelity, a pesar de que en sus comienzos se añadió junto con el nombre Wi-Fi la frase “The Standard for Wireless Fidelity” con el fin de dar significado al mismo, sino que fue creado como un juego de palabras relacionado con Hi-Fi (High Fidelity).

Resaltando sus principales características, se podría decir que las Redes Inalámbricas Wi-Fi son muy fáciles de adquirir, no tanto de configurar y muy difíciles de proteger.

Por último, cabe aclarar que la tecnología Wi-Fi no es compatible con otros tipos de conexiones wireless como Bluetooth, GPRS, UMTS, etc.

2.3. WLAN vs LAN

La norma IEEE 802.11 fue diseñada para sustituir a las capas físicas y de enlace de las redes Ethernet (802.3) especificando su funcionamiento en redes WLAN (redes wireless de área local), por lo que las redes Wi-Fi y las Ethernet son idénticas salvo en el modo en el que los terminales acceden a la red, lo que supone compatibilidad entre ambas.

Las principales diferencias entre las redes cableadas Ethernet y las redes inalámbricas Wi-Fi son:

2.3.1. Medio de transmisión

Mientras las redes cableadas utilizan un medio exclusivo como es el cable, las redes Wi-Fi utilizan el aire, un medio compartido.

2.3.2. Señalización

Ethernet utiliza señales eléctricas y Wi-Fi ondas de Radiofrecuencia.

2.3.3. Seguridad

Al utilizar cableado Ethernet “no permite”, al menos tan fácilmente, que la información sea vista por extraños. Sin embargo con las redes inalámbricas la información puede ser capturada por cualquiera.

La comodidad conseguida gracias a la movilidad que ofrece la tecnología Wi-Fi, junto con la supresión del cableado son sin duda alguna los puntos fuertes de este tipo de redes. Sin embargo a su vez aparecen desventajas como la pérdida de velocidad en comparación con redes cableadas, debida a las interferencias y pérdidas de señal que el medio puede provocar.

Como se verá más adelante el principal problema que surge en las redes WLAN es la debilidad de su seguridad, ya que con las herramientas apropiadas en pocos minutos la contraseña de red se puede ver comprometida si no es correctamente protegida. Con el fin de solucionar este problemas la Wi-Fi Alliance hizo pública la clave WPA y posteriormente la WPA2, un nuevo tipo de clave mucho más robusta que las WEP, pero todo esto será explicado con más detenimiento en el apartado de seguridad.

2.4. Historia

En 1999 los principales vendedores de soluciones inalámbricas (3com, Aironet, Intersil, Lucent Technologies, Nokia y Symbol Technologies) crearon una asociación conocida como WECA, con el fin de resolver el problema que suponía la existencia de diferentes estándares, lo que provocaba problemas de incompatibilidad. Por lo tanto esta asociación se propuso crear una marca que permitiese fomentar la tecnología inalámbrica y asegurar la compatibilidad de los dispositivos.

Es en el año 2000 cuando WECA con la norma IEEE 802.11b certifica la interoperabilidad de equipos bajo la marca Wi-Fi, con lo que se garantiza que todos los elementos con el sello Wi-Fi pueden trabajar juntos sin problemas independientemente del fabricante de cada uno de ellos.

En 2002 la asociación, formada ya por casi 150 miembros, anuncia la marca Wi-Fi5 utilizada para certificar equipos IEEE 802.11a de la banda de 5 GHz, debido a que las velocidades máximas ofrecidas por la norma 802.11b (11 Mbps) había sido superada.

2.5. Protocolos

Desde 1997, cuando se certificó el primer estándar 802.11 con una velocidad de transferencia máxima de 2 Mbps, han ido surgiendo nuevos estándares que permiten velocidades cada vez mayores y con distintas bandas de frecuencias, alcanzando hoy en día hasta 300 Mbps.

A continuación se describen los diferentes protocolos para redes Wi-Fi que han sido certificados como estándares desde la aparición del IEEE 802.11.

2.5.1. 802.11 legacy

Publicado en 1997, es la versión original del estándar IEEE 802.11. Permitía dos velocidades teóricas de transmisión, 1 y 2 Mbps, mediante señales infrarrojas en la banda ISM (Industrial, Scientific and Medical, de uso no comercial) a 2,4 GHz.

Este estándar definía el protocolo CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) como método de acceso. Una parte importante de la velocidad de transmisión se utiliza en las necesidades de esta codificación para mejorar la calidad de la transmisión bajo condiciones ambientales diversas, lo que produjo dificultades de interoperabilidad entre equipos de diferentes marcas y rechazo entre los consumidores.

En la actualidad no se fabrican productos sobre este estándar.

2.5.2. 802.11a

Creado en 1997, no fue aprobado hasta 1999, cuando lo hizo junto con el 802.11b, y apareció en el mercado en productos en el 2001.

Este estándar utiliza el mismo protocolo de base que el estándar original, pero opera en la banda de 5 GHz y utiliza 52 subportadoras OFDM (Orthogonal Frequency Division Multiplexing) con una velocidad máxima de 54 Mbps, lo que hace que sea un estándar práctico para redes inalámbricas con velocidades reales de unos 20 Mbps.

No puede interoperar con equipos del estándar 802.11b, a menos que dicho equipo implemente ambos estándares.

Un punto a favor para este protocolo es que al utilizar la banda de frecuencias de 5 GHz se presentan muchas menos interferencias, debido a que la banda de 2.4 GHz es utilizada por una gran cantidad de aparatos domésticos. Como contrapartida esta banda restringe el uso de los equipos a puntos en línea de vista, lo que requiere una instalación de un mayor número de puntos de acceso y a una cobertura menor. Algo que priori es negativo puede suponer una ventaja en instalaciones donde se desea que el rango de cobertura sea pequeño. Este protocolo conserva su velocidad máxima de 54 Mbps en un rango de 30 metros en el exterior y de 12 metros en el interior.

2.5.3. 802.11b

Certificado en 1999, corrige las principales debilidades del estándar original y es el primer protocolo de la familia en ser aceptado por los consumidores.

Permite una velocidad máxima de transmisión de 11 Mbps trabajando en la misma banda de frecuencia de 2.4 GHz. También utiliza el método de acceso CSMA/CA lo que reduce en la práctica la velocidad máxima de transmisión a 5.9 Mbps sobre TCP y a 7.1 Mbps sobre UDP.

2.5.4. 802.11g

Aprobado en 2003, al igual que el 802.11b utiliza la banda de 2.4 GHz y es compatible con el mismo, pero opera con una velocidad teórica máxima de 54 Mbps (unos 24.7 Mbps de velocidad real), semejante a la del 802.11a.

El diseño del estándar se realizó pretendiendo hacerlo compatible con el 802.11b, pero en redes bajo el estándar g, la presencia de nodos bajo el estándar b reduce significativamente la velocidad de transmisión.
Esto es así porque 802.11g implementa OFDM (Multiplexación por División de Frecuencias Ortogonales), algo que 802.11b no contempló. En presencia

de una red 802.11b, una red 802.11g puede transmitir a un máximo de 22Mbps.

En la actualidad se comercializan equipos con esta especificación que, con potencias de hasta medio vatio, permiten establecer comunicaciones de hasta 50 km de distancia mediante antenas parabólicas apropiadas.

2.5.5. 802.11h

Aparece en 2003 como una modificación del 802.11a con el fin de resolver los problemas derivados de la coexistencia de las redes Wi-Fi con sistemas de radares y satélites, debido a que la banda de 5 GHz era utilizada generalmente por sistemas militares.

Este nuevo protocolo proporciona a las redes 802.11a la capacidad de gestionar dinámicamente tanto la frecuencia, como la potencia de transmisión mediante las siguientes funcionalidades:

DFS (Dynamic Frequency Selection): Permite evitar interferencias con sistemas de radar y asegurar una utilización uniforme de los canales disponibles.
TPC (Transmitter Power Control): Asegura que se respetan las limitaciones de potencia transmitida que puede haber para diferentes canales en una determinada región, de manera que se minimiza la interferencia con sistemas de satélite.

2.5.6. 802.11n

La norma 802.11n supone una mejora espectacular con respecto a las tres normas que la preceden. Promete alcanzar velocidades de hasta 600Mbps. Actualmente solo se venden equipos capaces de transmitir a 300Mbps (teóricos), que el usuario percibe como 100Mbps.

802.11n se basa en los estándares anteriores, pero hace uso de tecnología MIMO (multiple input, multiple output) para emplear más de un canal a la vez. De este modo el equipo receptor puede, por ejemplo, percibir las señales que llegan reflejadas (y por tanto con un poco de retardo).

Además, hace uso de channel bonding, una característica que incrementa el ancho de banda de cada canal a 40MHz. Y, como ya sabemos, a mayor ancho de banda, mayor capacidad de transmisión de datos. Aunque no deberíamos activar esta característica en nuestro router si a nuestro alrededor hay más equipos que hagan uso de la banda de los 2,4GHz (particularmente Bluetooth y otros vecinos con routers b/g/n).

2.5.7. 802.11e

Este estándar permite soportar tráfico en tiempo real en todo tipo de entornos y situaciones. El objetivo de este estándar es introducir nuevos mecanismos a nivel de enlace para soportar los servicios que requieren garantías de Calidad de Servicio (QoS).

Para conseguir dicho objetivo el protocolo introduce un nuevo elemento, el HCF (Hybrid Coordination Function), con dos tipos de acceso:

EDCA: Enhanced Distributed Channel Access.

HCCA: Controlled Channel Access.

2.5.8. 802.11i

Este protocolo está dirigido a batir la vulnerabilidad actual en la seguridad para protocolos de autenticación y de codificación, abarcando los protocolos 802.1x, TKIP (Protocolo de Claves Integra – Seguras – Temporales), y AES (Estándar de Cifrado Avanzado).

2.5.8. 802.11 Super G

Trabaja en la banda de 2.4 GHz y gracias al chipset Atheros alcanza velocidades de transferencia de 108 Mbps.

2.5.9. 802.11 ac

Es el último estándar en aprobarse en Enero de 2014, y es una evolución del estándar 802.11n. El estándar consiste en mejorar las tasas de transferencia hasta 1 Gbit/s dentro de la banda de 5 GHz, ampliar el ancho de banda hasta 160 MHz (40 MHz en las redes 802.11n), hasta 8 flujos MIMO y modulación de alta densidad (256 QAM).

De momento hay muy pocos dispositivos que tengan soporte para este estándar (algunos puntos de acceso y algunas tarjetas de red, incluyendo las de las últimas versiones de iMac y Macbook Air de Apple). Pero en todo lo que va del año 2013 ya se han lanzado varios dispositivos compatibles con este protocolo, y obviamente para 2014 ya será mucho mas común.

2.5.10. El futuro: 802.11ad

El protocolo 802.11ad permitirá velocidades de transferencia de hasta 7 Gbps, para conseguirlo hace uso de la banda de 60GHz (típicamente entre 57 y 66 GHz) mediante la cual proporciona enlaces inalámbricos de corto alcance y generalmente en línea de visión directa (sin obstáculos como paredes o techos).

Debido a esta restricción, el 802.11ad no es un estándar pensado para conectar a Internet a los diferentes dispositivos de nuestros hogares, como actualmente lo son las tecnologías WiFi o el 802.11ac que operan en las bandas de 2,4 y 5 GHz.

El nuevo estándar está pensado para comunicaciones directas de gran velocidad y corto alcance entre equipos como ordenadores, móviles, tabletas, discos de red y televisores, tanto para vídeo en streaming en HD o UHD sin cables como para pasar grandes cantidades de datos de forma inalámbrica entre por ejemplo un disco duro y un ordenador.

En la especificación ha colaborado la Wireless Gigabit Alliance (WiGig), que recientemente unió fuerzas con la Wi-Fi Alliance, y aunque todavía no existen dispositivos compatibles, se espera que los primeros comiencen a llegar al mercado a finales de este mismo año.

2.6. Perspectiva

Parece que las tecnologías Wi-Fi y las de consumo relacionadas son la clave para reemplazar a las redes de telefonía móvil como GSM. Sin embargo existen obstáculos para que esto ocurra en un futuro próximo como la pérdida del roaming (cambio entre zonas de cobertura), la autenticación más precaria y la estrechez del espectro disponible.

A pesar de estos inconvenientes, compañías como SocketIP y Symbol Technologies están ofreciendo plataformas telefónicas (centrales y terminales) que utilizan tecnología Wi-Fi.

La plataforma GOWEX interconecta muchos operadores, consiguiendo una red global Wi-Fi que permita la movilidad, solucionando los problemas relacionados con el roaming.

2.7. Dispositivos

2.7.1. Tipos

2.7.1.1. AP/WAP – Puntos de Acceso Wireless

Los puntos de acceso en redes Wi-Fi son los elementos que interconectan los distintos dispositivos de comunicación inalámbrica para formar una red wireless. Habitualmente estos dispositivos pueden conectarse a redes cableadas, permitiendo intercambiar información entre dispositivos cableados y wireless. De la misma manera, distintos puntos de acceso pueden ser conectados permitiendo realizar roaming.

Son los encargados de crear la red, permaneciendo a la espera de nuevos clientes a los que dar servicios. El punto de acceso recibe la información, la almacena y la transmite entre la WLAN y la LAN cableada. Estos dispositivos tienen direcciones IP asignadas, para poder ser configurados.

Desde un único punto de acceso se puede dar soporte a un grupo de usuarios y trabajar en un rango desde unos 30 a varios cientos de metros, siempre en función de las antenas utilizadas.

Los Puntos de Acceso pueden ser agrupados en dos categorías:

Puntos de Acceso Robustos. Son bastante inteligentes e incorporan funciones adicionales de gestión y seguridad, como Firewall, Site Survey o no emitir el ESSID (algo que se comentará más adelante). Además son más costosos y complicados de gestionar y suelen sobrecargar el tráfico. En algunos casos disponen de slots libres para futuras actualizaciones.

Puntos de Acceso Básicos. Son más económicos y sencillos de gestionar y configurar, además suele ser más sencillo compatibilizarlos con otras marcas.

2.7.1.2. Routers

Los routers reciben la señal de la línea que ofrezca el operador de telefonía y se encargan de todos los problemas relacionados a la recepción de la señal, como el control de errores y la extracción de la información, para que los diferentes niveles de red puedan trabajar.

Los routers trabajan de manera conjunta con los puntos de acceso wireless, funcionando estos últimos a modo de emisor remoto, es decir, en lugares donde la señal Wi-Fi del router no tenga suficiente radio.

Otros dispositivos como hubs o switches también pueden encargarse de la distribución de la señal, pero no pueden encargarse de las tareas de recepción.

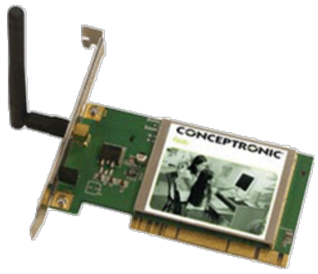
Hoy en día la mayoría de los Puntos de Acceso incluyen las funcionalidades de los Routers, por lo que estos se están viendo sustituidos.

2.7.1.3. Tarjetas de Red Wi-Fi

Son los dispositivos encargados de la recepción de información en estaciones de redes Wi-Fi. Una de las principales características que las diferencian entre sí es el tipo de interfaz que utilizan, es decir, el puerto de conexión de la tarjeta.

A continuación se describen los diferentes tipos de tarjetas en función de la interfaz que utilizan:

- **PCI:** Peripherial Component Interconnect, bus de interconexión de componentes periféricos, que conecta directamente a la placa base de la computadora dispositivos periféricos (bus local). Permite configurar el dispositivo de manera dinámica y suele ser utilizado en ordenadores de sobremesa. Habitualmente suele disponer de conectores para antenas.



- **Mini PCI:** Este tipo de tarjetas posee características semejantes a las PCI, pero su tamaño es mucho menor, se utiliza en portátiles y no dispone de conectores para antenas.

- **PCMCIA:** Personal Computer Memory Card Internacional Association, es un dispositivo utilizado habitualmente en portátiles, la mayoría de estas tarjetas solo son capaces de llegar a la tecnología 802.11b, no permitiendo disfrutar de una velocidad de transmisión demasiado elevada. Las tarjetas PCMCIA también reciben el nombre de PC Card si son de 16 bits o CARD BUS si son de 32 de bits.

- **USB:** Universal Serial Bus, provee un estándar de serie para conectar dispositivos a un PC. Hoy en día el USB se ha convertido en el método de conexión más usado, debido a su

dinamismo, desplazando otros estándares de conexión. Las tarjetas wireless USB son fáciles de instalar, sin embargo, en algunos casos no son tan potentes como las anteriores, esto es en cuanto a velocidad, encriptación o alcance. Pueden ser utilizadas tanto en portátiles como en PCs de sobremesa, y además existe una gran variedad de modelos que implementan los distintos protocolos 802.11, incluso algunos todavía no estandarizados.

- **CENTRINO:** Centrino Mobile Technology es una iniciativa de Intel para promocionar una combinación preestablecida de CPU, chipset de la placa base e interfaz de red inalámbrica en el diseño de ordenadores personales portátiles. La interfaz de red es del tipo Intel PRO/Wireless 2100 (802.11b) o PRO/Wireless 2200 (802.11g).

Todo lo mencionado correspondía simplemente al tipo de interfaz que utiliza la tarjeta Wi-Fi, sin embargo a la hora de considerar una tarjeta wireless, sobre todo para la tarea de auditorías, es conocer el chipset y los drivers que utiliza, que no tienen porque ser desarrollados por la compañía que ha fabricado la tarjeta Wi-Fi.

2.7.2.4. Antenas

Habitualmente las placas de red inalámbricas disponen de antenas incorporadas diseñadas para un uso en interiores y con un rango de alcance bastante reducido. Para un proceso de auditoría o para cubrir mayores superficies, como pueden ser edificios o vecindarios resultaría conveniente utilizar antenas especializadas.

Las características de una antena pueden ser clasificadas, además de por su alcance, según su:

Patrón de radiación:

- *Omnidireccionales:* Cubren áreas grandes, intentando que la radiación sea pareja en 360º.

- *Bidireccionales:* Buenas para pasillos y corredores dado que radia o recibe la mayoría de la energía en dos direcciones.
- *Unidireccionales o Direccionales:* Son las más apropiadas en conexiones punto a punto o para clientes de una antena omnidireccional.

Ganancia: Es el cociente entre la intensidad de campo producida por la antena y la intensidad de campo que produciría en el mismo punto un radiador isotópico que absorbiera del emisor la misma potencia de RF. La ganancia de las antenas se mide en dBi.

Considerando estas dos características, a continuación se describen los distintos tipos de antenas existentes:

- **Vertical:** Es una antena omnidireccional con ganancias que van desde los 3 dBi hasta los 17 dBi. Por ser omnidireccionales son antenas buenas en la radiación en plano horizontal.

- **Yagi:** Es un tipo de antena unidireccional de alta ganancia. Se asemeja a una antena clásica de TV, las Yagis pueden alcanzar ganancias de entre 12 y 18 dBi y son más fáciles de apuntar que las antenas parabólicas.

- **Parabólica:** Las antenas parabólicas tienen una ganancia muy alta, de hasta 27 dBi en antenas comerciales Wi-Fi, pero debido a que la radiación que propaga o puede recibir es muy estrecha no es apropiada para usuarios que no ven directamente la antena. Al igual que las Yagi, las antenas parabólicas son más apropiadas para conexiones punto a

punto, como conexiones entre edificios, o para utilizarlas conjuntamente con antenas verticales de alta ganancia.

2.7.2. Modos de funcionamiento

Los dispositivos encargados de la comunicación Wi-Fi, Puntos de Acceso o Tarjetas de Red, pueden utilizar diferentes tipos de funcionamiento:

- **Modo Managed.** Modo en el que las Tarjetas Wi-Fi se conectan al AP para que éste último le sirva de concentrador. La Tarjeta de Red sólo se comunicará con el Punto de Acceso.
- **Modo Master.** Es el modo de funcionamiento del Punto de Acceso, pero las Tarjetas de Red también pueden entrar en este modo si disponen del firmware apropiado o si están conectadas a una máquina que se puede encargar de realizar la funcionalidad requerida.
- **Modo Ad-Hoc.** Los dispositivos utilizan este método cuando la red a la que pertenecen es de topología Ad-Hoc, que será descrita a continuación, por lo que se deben preparar para recibir y enviar paquetes a todos los miembros de la red.
- **Modo Monitor.** También denominado RFMON, con este modo el dispositivo es capaz de capturar todo el tráfico que circula por la red, incluso los paquetes que no van dirigidos hacia él, es decir el firmware de la tarjeta pasa cualquier paquete recibido al controlador software. Como se verá más adelante, este modo es el utilizado por los atacantes para vulnerar la seguridad de los protocolos de cifrado de la red.
- **Modo Repeater.** El dispositivo reenvía los paquetes recibidos de otros nodos inalámbricos.
- **Modo Secondary.** Utilizado como backup de otro dispositivo que funciona en modo Master o Repeater.
- **Modo Auto.** Con este modo el dispositivo se configura de manera automática, empezando por Ad-Hoc y siguiendo en Manager.

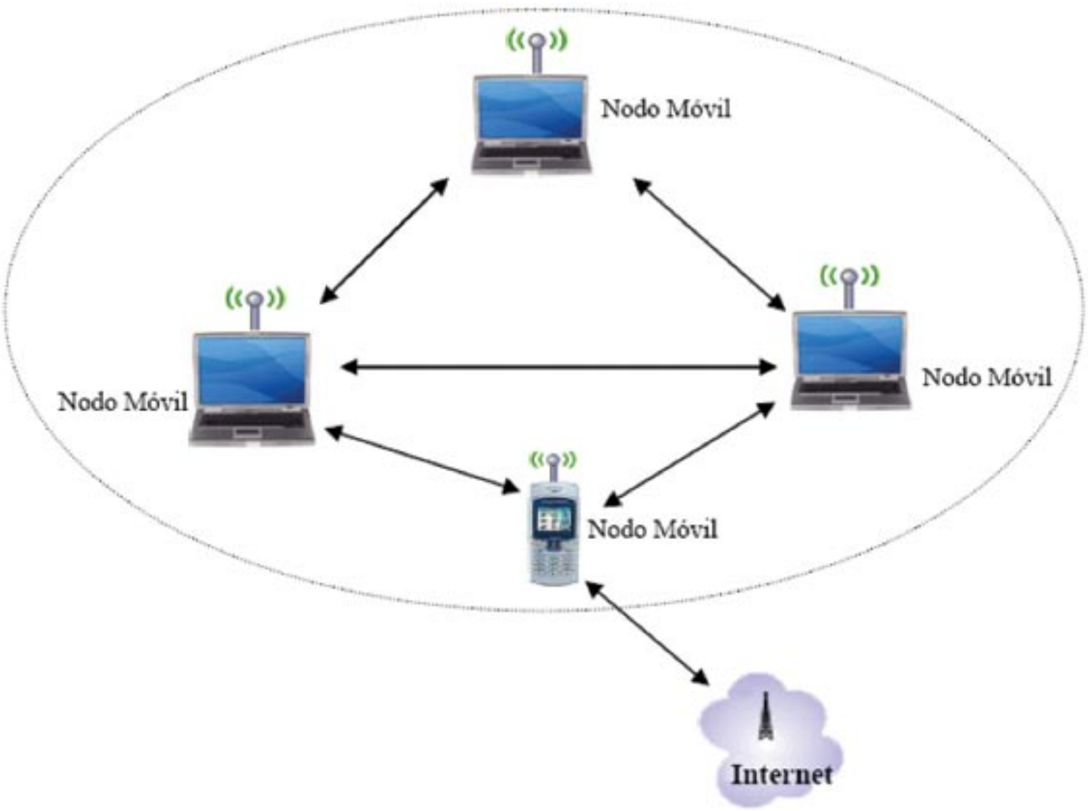
Estos modos de funcionamiento nos sugieren que tanto los Puntos de Acceso como las Tarjetas de Red Inalámbricas son dispositivos iguales a los que se les ha añadido cierta funcionalidad que los diferencia vía firmware o software.

2.8. Topología

Con topología nos referimos a la disposición lógica de los dispositivos, aunque la disposición física también puede verse influida. En las redes Wireless existen los siguientes tipos de topologías:

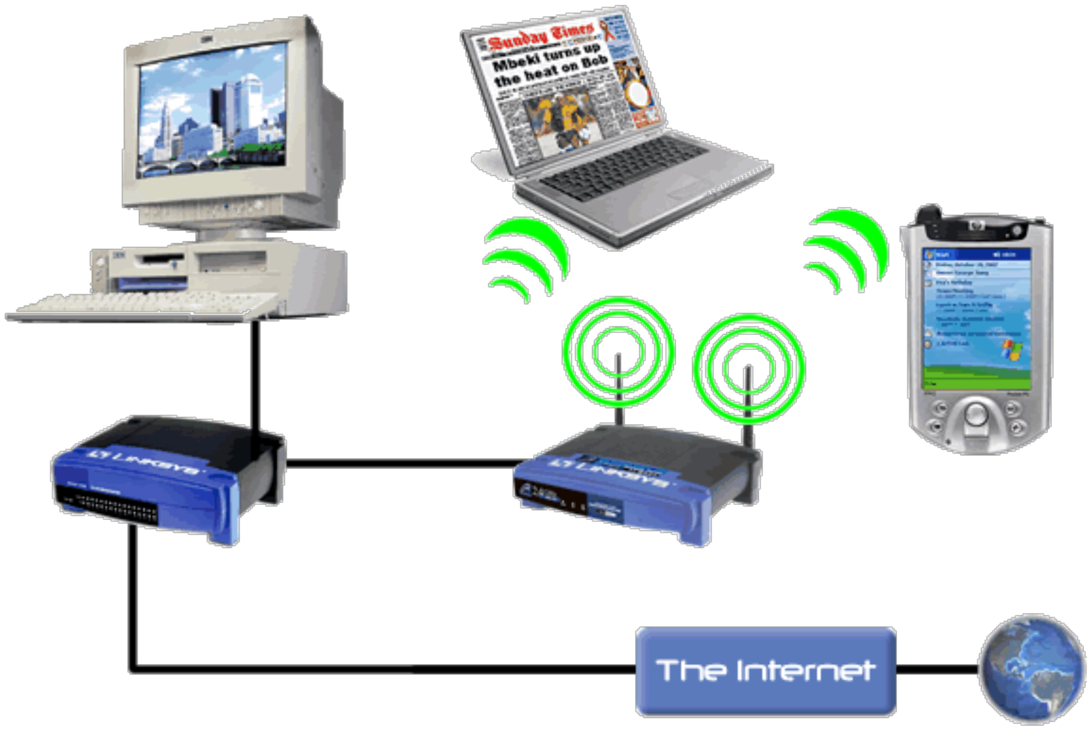
2.8.1. Topología Ad-Hoc

Cada dispositivo se puede comunicar con todos los demás, es decir, cada nodo forma parte de una red Peer to Peer, de igual a igual, formando una especie de red de grupos de trabajo. A más dispersión geográfica de cada nodo más dispositivos pueden formar parte de la red, aunque algunos no lleguen a verse entre sí, pero un gran número de dispositivos conectados a la red pueden hacer que el rendimiento se vea reducido.



2.8.2. Topología Infraestructura

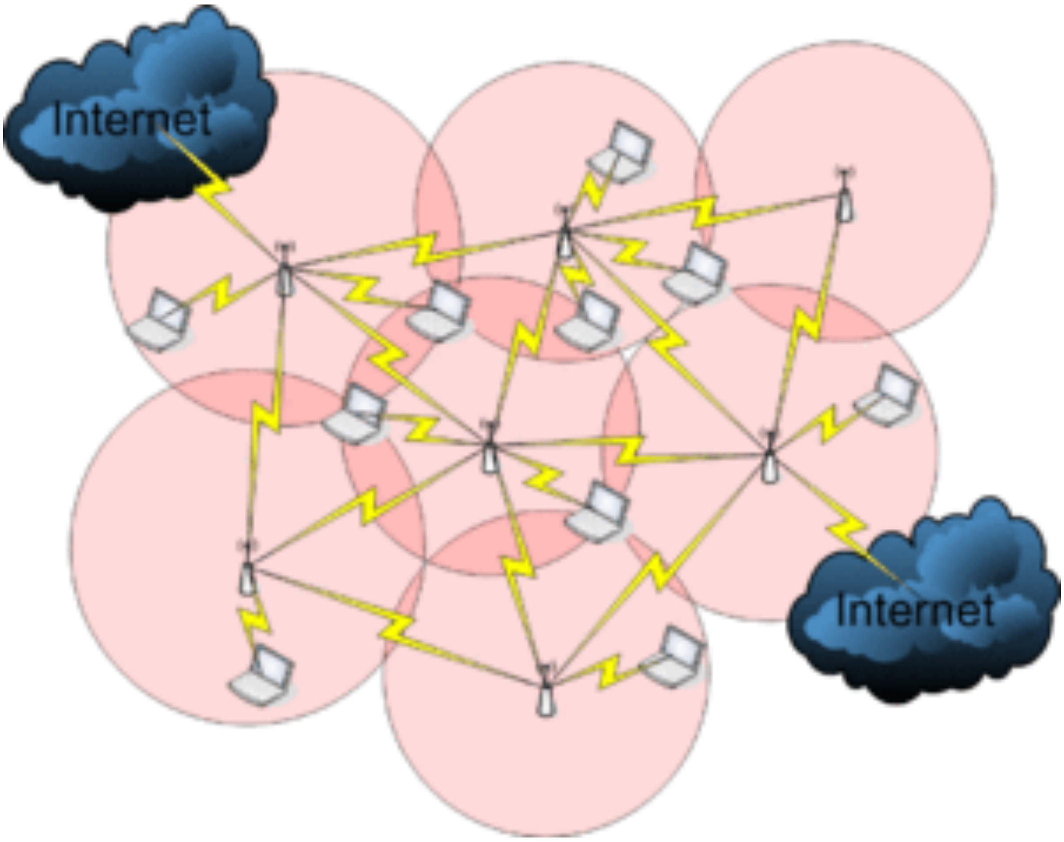
Un nodo central, el Punto de Acceso, sirve de enlace para todos los demás, las Tarjetas de Red Wi-Fi, encaminando las tramas hacia una red convencional o hacia otras redes distintas. Para poder establecerse la comunicación, todos los nodos deben estar dentro de la zona de cobertura del AP.



2.8.3. Topología Mesh

Las redes Mesh, o red inalámbrica mallada, son aquellas redes en las que se mezclan las dos topologías de las redes inalámbricas. Básicamente son redes con topología de infraestructura, pero que permiten unirse a la red a dispositivos que están fuera del rango de cobertura del Punto de Acceso pero dentro del de algún dispositivo móvil asociado a la red.

También permiten la comunicación entre los dispositivos móviles independientemente del Punto de Acceso. Para hacer esto posible un protocolo de enrutamiento se encarga de transmitir la información hasta su destino con el mínimo número de saltos.



2.9. Transmisión de la información

2.9.1. Tipos de paquetes

La información en las redes Wi-Fi es transmitida por RF, Radio Frecuencias, a través del aire, en forma de paquetes. El estándar IEE 802.11 define distintos tipos de paquetes con diversas funciones. Hay 3 tipos diferentes de paquetes que pasaremos a analizar de manera breve a continuación.

2.9.1.1. Paquetes de Management

Establecen y mantiene la comunicación.

- **Association Request.** Incluye información necesaria para que el Punto de Acceso considere la posibilidad de conexión. Uno de los datos principales es el ESSID o nombre de la red inalámbrica al que se intenta conectar.
- **Association Response.** Paquete enviado por el AP avisando de la aceptación o denegación de la petición de conexión.
- **Beacon.** Los Puntos de Acceso Wi-Fi envían paquetes periódicamente para anunciar su presencia y que todas las estaciones que estén en el rango de cobertura sepan que el AP está disponible. Estos paquetes se denominan “Beacons” y contienen varios parámetros, entre ellos el ESSID del Punto de Acceso.
- **Probe Request.** Lo envían las estaciones para buscar redes Wi-Fi de forma activa, ya que se indicarán tanto el ESSID como la frecuencia de dichas redes.
- **Probe Response.** Son paquetes de respuesta ante los Probe Request, enviados por el AP, confirmando o rechazando transacciones.
- **Authentication.** Paquete por el que el Punto de Acceso acepta o rechaza a la estación que pide conectarse. Como se verá en el apartado de seguridad existen redes WiFi abiertas donde no se requiere autenticación y otras protegidas donde se intercambian varios paquetes de autenticación con desafíos y respuestas para verificar la identidad del cliente.

- **Desauthentication.** Lo envía el Punto de Acceso para eliminar una autenticación existente.
- **Disassociation.** Es enviado por una estación cuando desea terminar la conexión, de esta manera el AP sabe que puede disponer de los recursos que había asignado a esta estación

2.9.1.2. Paquetes de Control

Estos paquetes tienen funciones de coordinación, ayudan en la entrega de datos.

- **Request to Send (RTS).** Su función es la de evitar colisiones. Es la primera fase antes de enviar paquetes de datos.
- **Clear to Send (CTS).** Paquete para responder a los RTS. Todas las estaciones que captan un CTS saben que deben esperar un tiempo para transmitir, pues alguien está usando ya el canal. El tiempo de espera no es el mismo para todos los estándares.
- **Acknowledgement (ACK).** La estación receptora de cada paquete comprueba al recibirlos que no tiene errores. Si el paquete se encuentra correctamente, envía un ACK con lo cual el remitente sabe que el paquete llegó correctamente. Si el remitente no recibe el ACK deberá reenviar el paquete de nuevo. Una vez que las demás estaciones captan el ACK, saben que el canal está libre y que pueden enviar sus paquetes.

2.9.1.3. Paquetes de Datos

Estos paquetes llevan mucha información administrativa y, además, los datos que queremos transmitir a través de la red wireless. Generalmente cuando se desea enviar un archivo de datos la Red Wi-Fi deberá utilizar muchísimos paquetes de datos.

Los Paquetes de Datos WiFi, contienen información necesaria para la transmisión como la dirección MAC de la estación receptora y del remitente, el número de secuencia de ese paquete, etc.

2.9.2. Calidad de la señal

Las ondas de RF transmitidas por las redes WiFi son atenuadas e interferidas por diversos obstáculos y ruidos. Lo que se transmite es energía, y esta es absorbida y reducida.

A medida que nos alejemos del Punto de Acceso la calidad de la señal se verá atenuada debido a la presencia de paredes o a las transmisiones de otros dispositivos.

Las velocidades teóricas de los distintos estándares, en la práctica, son mucho menores, pues la velocidad de transmisión de una red inalámbrica Wi-Fi, será función de la distancia, los obstáculos y las interferencias, que pueden depender del tipo de construcción del edificio, micro-ondas, teléfonos inalámbricos, dispositivos Bluetooth, elementos metálicos, peceras , humedad del ambiente, etc., que se encuentren en el radio de acción del dispositivo Wi- Fi.

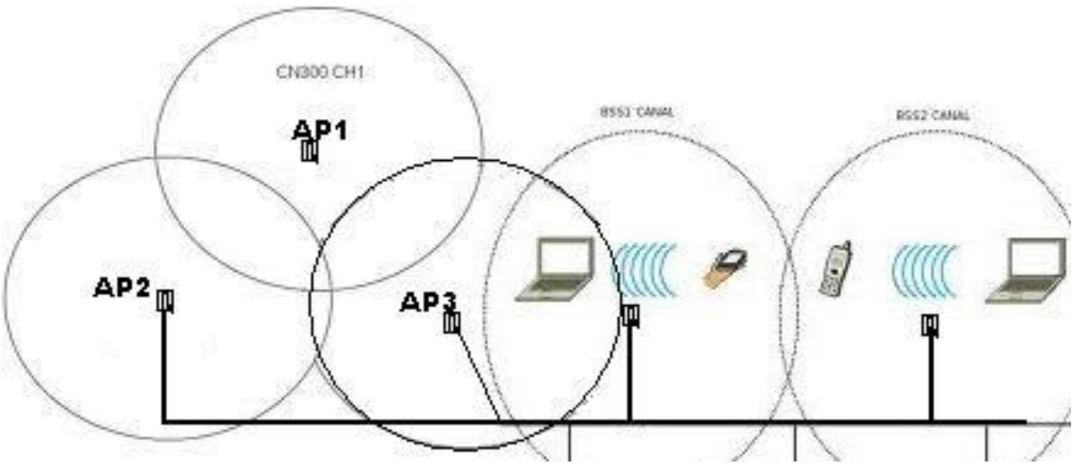
Como se comentó en el apartado de estándares 802.11, estos factores afectan a los estándares que actúan en la banda de 2.4 GHz. El 802.11a que actúa en la banda de 5 GHz evita gran cantidad de interferencias, pues no es utilizada prácticamente por ningún dispositivo inalámbrico doméstico.

Además las velocidades se verán afectadas por un hecho básico: Los usuarios de un Punto de Acceso deben compartir el ancho de banda, es decir, a mayor número de usuarios menor será el ancho de banda disponible para cada uno.

Un método para aumentar la capacidad de una Red Wi-Fi, es el uso de celdas, siendo una celda el área que cubre la señal de un AP, de tamaño reducido de manera conjunta, es decir, utilizar simultáneamente múltiples micro-celdas, consiguiendo así mejorar la calidad de la señal para los usuario de la red. Este concepto se desarrolla más profundamente a continuación.

2.9.3. Itinerancia

Dadas las limitaciones de cobertura que ofrecen los Puntos de Acceso Wi-Fi, una solución para ampliar el radio de una Red Wireless es implantar varios APs y permitir el roaming, o itinerancia, y movilidad de los usuarios. Para que esto funcione debe existir un solapamiento entre las zonas de cobertura de los Puntos de Acceso que permita al usuario pasar de estar asociado a un Punto de Acceso A a otro B sin perder la conexión.



Como se comentó en el apartado sobre los tipos de paquetes, los Puntos de Acceso envían periódicamente paquetes Beacon, cuando una estación se aleja de un Punto de Acceso comienza a dejar de recibir estos paquetes, es decir, se pierde la señal. Si hay superposición de Puntos de Acceso, mientras se pierde la señal de un AP empieza a aumentar la señal de otro.

Si se están enviando paquetes al Punto de Acceso, la estación esperará la recepción de las tramas ACK, también comentadas anteriormente. Si se aleja demasiado la estación dejará de recibir estos paquetes de confirmación. Los equipos Wi-Fi incorporan un algoritmo de decisión que determina el momento en el que debe desasociarse de una AP para hacerlo con otro de la misma red que le ofrece mejor calidad de señal.

El problema de todo esto es que el funcionamiento del Roaming no está estandarizado, por lo que cada fabricante implementa sus propios algoritmos de decisión, lo que puede provocar problemas al utilizar Puntos de Acceso y dispositivos móviles de distintas marcas.

2.9.4. Interferencias entre clientes

Los motivos más frecuentes de problemas entre los clientes de una Red Wi-Fi, y difíciles de detectar, son las interferencias entre clientes y los nodos ocultos.

En el apartado "Tipos de paquetes" se vio que mediante los Paquetes de Control se conseguían evitar las colisiones entre los paquetes transmitidos en una Red Wireless Wi-Fi. Cuando un cliente transmitía era porque había recibido un paquete CTS, por lo que los demás debían callar. Cuando, por algún motivo, un cliente de la red no puede captar los paquetes de otro cliente se produce una descoordinación y puede que ambos intenten transmitir a la vez, produciéndose así colisiones en la red.

Un problema que puede surgir, es que existan Puntos de Acceso solapados, y que un cliente del AP A que quiere transmitir reciba un CTS. Si este CTS es captado por un cliente del AP B puede quedarse callado durante un tiempo determinado, perdiendo así rendimiento de manera inútil.

En cuanto al problema de los nodos ocultos, si en un Punto de Acceso están asociados dos clientes, situados cada uno en extremos opuestos de la zona de cobertura del AP y no pueden captar los RTS y CTS de la otra estación es probable que intenten transmitir a la vez, produciendo colisiones, o que se callen las dos a la vez, causando gran ineficiencia en la red, que provocará grandes demoras y una baja calidad de servicio.

2.10. Seguridad

2.10.1. Wi-Fi y seguridad

Uno de los principales problemas que afectan a esta tecnología es la seguridad. La mayoría de redes instaladas por las operadoras de Internet o por administradores de redes no consideran la seguridad y, por tanto, convierten sus redes en redes abiertas, sin proteger la información que circula por ellas.

Antes de entrar más en detalle sobre la seguridad de este tipo de redes, cabe definir que significa seguridad en el mundo informático. Se dice que una red es segura cuando casi nadie externo a la red puede tener acceso a la mismo o los métodos de acceso son tan costosos que prácticamente nadie puede llevarlos a cabo. Ese casi nadie supone un 0.01 % de los posibles atacantes, es decir, no existen sistemas informáticos seguros al 100%. Por lo tanto, se puede decir que un sistema es seguro cuando tiene la protección adecuada al valor de la información que contiene.

Existen varios métodos de protección para este tipo de redes, sin embargo, cabe destacar, como acabamos de comentar, que ninguna de ellas proporcionará una seguridad absoluta, pero puede dificultar la tarea del atacante hasta un punto en el que decida cesar en su empeño.

Las redes wireless, a diferencia de las redes cableadas, poseen un punto débil en seguridad en el medio utilizado para la transmisión. Mientras las redes Ethernet utilizan un medio privado como el cable, las redes inalámbricas utilizan el aire, un medio compartido y altamente inseguro.

El hecho de no disponer de redes WiFi en una organización, o tenerlas bien aseguradas, no tiene por que suponer que el sistema sea seguro, ya que con que exista algún dispositivo Wi-Fi, como portátiles con tarjetas de red inalámbricas, el sistema se torna vulnerable y frágil. Es decir, el peligro no reside realmente en las propias redes, sino en la tecnología Wi-Fi.

A continuación se describirán las principales medidas de seguridad que se pueden establecer para una red Wi-Fi.

2.10.2. Medidas de seguridad

2.10.2.1. Protocolos de cifrado

- **WEP (Wired Equivalent Privacy)**

Desde el comienzo de los estándares 802.11 algunas debilidades como la transmisión de datos "en claro" a través de un medio accesible por todo el mundo como el aire provocó la aparición del nuevo estándar 802.11b que proporcionaba un mecanismo de seguridad que permitía encriptar las comunicaciones. Esta medida de protección fue denominada Wired Equivalent Privacy, es decir, una privacidad equivalente a la de las redes cableadas.

Gracias a la estandarización de este protocolo era posible encriptar el tráfico entre los Puntos de Acceso y las estaciones móviles y compensar la falta de seguridad inherente a una Red Wireless.

El protocolo WEP se basa en el algoritmo de encriptación RC4 y el algoritmo de chequeo CRC, estableciendo una clave secreta en el Punto de Acceso compartida con los clientes Wi-Fi autorizados. Gracias al algoritmo RC4 y un Vector de Inicialización (IV) se realiza la encriptación de los datos transmitidos por radio frecuencia.

Con el aumento de popularidad y la difusión de las Redes Wi-Fi aumentaron también las vulnerabilidades descubiertas sobre el protocolo WEP que podían ser explotadas provocando graves problemas de seguridad en la red comprometida y generando mala prensa sobre el uso de este tipo de redes.

El principal foco de problemas de seguridad se debía al Vector de Inicialización IV utilizado con el algoritmo de cifrado RC4. Este algoritmo es de cifrado de flujo, es decir, que funciona expandiendo una semilla (en este caso el IV) para generar una secuencia de números pseudoaleatorios de mayor tamaño que se unirá mediante un XOR con el mensaje, formando así el mensaje cifrado.

El IV independientemente del tamaño de la clave (64 o 128 bits) siempre es de 24 bits, un tamaño demasiado pequeño lo que ocasiona que en redes con mucho tráfico no todos los IVs generados serán distintos, además en ciertos dispositivos clientes muy simples el primer IV es 0, el siguiente 1 y así sucesivamente, lo que permite descifrar la clave de encriptado de una manera muy sencilla ya que para que el algoritmo RC4 sea efectivo las semillas no se deben repetir.

Adicionalmente al problema de los IVs el hecho de que las claves utilizadas sean estáticas y que deban ser cambiadas manualmente provoca que no se suelan cambiar habitualmente lo que también facilita que sean descubiertas. Por último otro de los principales puntos débiles del protocolo WEP es la falta de un sistema de control de secuencia de paquetes, por lo que durante una transmisión no se podrá detectar si algún paquete ha sido robado o modificado.

Las posibilidades de explotar estas vulnerabilidades hicieron que apareciesen aplicaciones que pueden romper la seguridad de este protocolo de una manera relativamente sencilla como se podrá comprobar con la herramienta desarrollada en este Proyecto.

A pesar de existir otros protocolos de cifrado mucho menos vulnerables y eficaces, como los que se mostrarán a continuación, WEP sigue siendo muy utilizado debido a su facilidad de configuración y a que es soportado por cualquier sistema con el estándar 802.11

- **WPA (Wifi Protected Access)**

Promovido por la WiFi Alliance, WPA surgió con el fin de solucionar las debilidades que habían sido detectadas en el protocolo de encriptación WEP de una manera rápida y temporal que permitiese funcionar con los Puntos de Acceso y dispositivos Wi-Fi existentes. La parte técnica está definida y estipulada en el estándar de seguridad IEEE 802.11i.

Antes de aparecer WPA, entre 2001 y 2002, los APs existentes tenían la capacidad de su hardware ocupada casi en su totalidad con diversas funciones, por lo que las modificaciones que se pretendiesen realizar sobre WEP, no podrían requerir mucha capacidad de proceso.

Aprobado en 2003 y declarado obligatorio a finales del mismo año, el conocido como WPA se basa en el uso de un protocolo llamado TKIP (Temporal Key Integrity Protocol), una envoltura del WEP, que cambia las claves dinámicamente a medida que el sistema es utilizado, además de en otras mejoras en la seguridad de las Redes Wi-Fi como la duplicación del tamaño del Vector de Inicialización de 24 a 48 bits, la aparición de una función MIC (Message Integrity Check) para controlar la integridad de los mensajes, detectando la manipulación de los paquetes, y un refuerzo del mecanismo de generación de claves de sesión.

Dentro del protocolo WPA existen 2 versiones, una personal para uso doméstico y en pequeñas empresas llamada *WPA-Personal* que utiliza una clave pre compartida (WPA-PSK) y otra más robusta utilizada en grandes organizaciones llamada *WPA-Enterprise* que utiliza un servidor de autenticación que distribuye claves diferentes a cada usuario, el cual, requiere
802.1x y EAP, algo sobre lo que se hablará más adelante.

Respecto a este protocolo se debe tener en cuenta que a pesar de haber sido declarado como obligatorio a partir de finales del 2003, los fabricantes miembros de la WiFi Alliance deben proporcionar gratuitamente a sus clientes un parche que permita actualizar los Puntos de Acceso antiguos de WEP a WPA. Este “parcheado” aumentará la seguridad, sin embargo causará que los APs se vuelvan más lentos y disminuya su rendimiento.

- **WPA2**

La WiFi Alliance utilizó WPA como una medida temporal para solucionar los problemas de WEP modificando este protocolo, pero con WPA2 la seguridad ofrecida era mucho mayor y más estable partiendo de bases distintas a las de WEP. Aunque WPA2 todavía mantiene el Vector de Inicialización de 48 bits, la nueva medida de protección se denomina CCMP que destierra el uso del algoritmo RC4 y, en su lugar, utiliza el algoritmo de encriptación AES, recomendado por el NIST (Instituto Nacional de Estándares y Tecnología), de los más fuertes y difíciles de “crackear” hoy en día, que utiliza un cifrado simétrico de 128 bits. Este algoritmo requiere un hardware más potente, por lo tanto, como se comentó antes, los Puntos de Acceso antiguos no se pueden utilizar con WPA2.

Este protocolo es la segunda fase del estándar IEEE 802.11i, las primeras certificaciones aparecen en el 2004 y desde Marzo de 2006 WPA2 es requisito obligatorio para todos los productos WiFi.

El nuevo estándar exigió cambios en los paquetes utilizados por las Redes WiFi para transmitir la información, teniendo que incluir datos sobre el tipo de encriptación (WEP, TKIP, CCMP) o sobre el tipo de autenticación (802.1x o contraseña) en paquetes como los “Beacon” o “Association Request”, una muestra más de por qué los dispositivos antiguos no funcionan con WPA2.

Por último, al igual que con WPA, existen 2 versiones de WPA2. Una personal *WPA2-Personal* que sólo requiere contraseña y otra empresarial *WPA2- Enterprise* que requiere 802.1x y EAP.

2.10.2.2. ACL – Filtro de Direcciones MAC

La dirección MAC (Media Access Control) es un número que identifica las interfaces físicas de los dispositivos que pueden establecer comunicaciones, esto es, tanto Tarjetas de Red como Puntos de Acceso, Routers, etc, suministrados por el fabricante.

El método ACL, Access Control List, consiste en suministrar a cada Punto de Acceso Wi-Fi un listado con las direcciones MAC de los equipos que están autorizados a conectarse a la red. De esta manera los equipos que no figuren en esta lista serán rechazados.

Es uno de los métodos de protección de Redes Wi-Fi más primitivos y menos eficaces que existen debido a una gran cantidad vulnerabilidades y desventajas.

2.10.2.3. Deshabilitado del Servidor DHCP

El Punto de Acceso puede asignar las direcciones dinámicamente a todos los clientes que se conecten, pero si deshabilitamos esta opción y permitimos el acceso sólo a determinadas direcciones IP, un extraño que se asocie al AP y no disponga de los parámetros de configuración correctos, como dirección IP, dirección de la puerta de enlace, etc., tendrá una conectividad a la red nula.

Esta medida es semejante a la de filtrado de direcciones MAC, con la diferencia de que las direcciones IP pueden ser enviadas cifradas, con lo que el atacante encontrará más problemas a la hora de acceder a la red.

2.10.2.4. CNAC – Ocultamiento del ESSID

El ESSID (Extended Service Set IDentifier) es un código formado por un máximo de 32 caracteres alfanuméricos incluido en todos los paquetes de una Red Wi-Fi para identificarlos como parte de esa red, a menudo conocido simplemente como nombre de la red.

El método CNAC, Closed Network Access Control, de los más básicos para la protección de una red inalámbrica, está basado en desactivar el broadcast del ESSID en las tramas beacon utilizadas para que las estaciones detecten los Puntos de Acceso, por lo que impide que los dispositivos que no conocen el ESSID puedan asociarse a la red.

El primer paso para atacar una red es detectar la misma, con esta medida de protección un usuario “medio” no podrá detectar nuestra red, sin embargo es una técnica de protección que al igual que las anteriores debe ser utilizada como una medida adicional al uso de otras, ya que con las herramientas apropiadas el ESSID puede ser descubierto de manera sencilla.

2.10.2.5. VPN – Redes Privadas Virtuales

Las Redes Privadas Virtuales permiten proteger las comunicaciones creando un túnel criptográfico entre los dos extremos, realizando una encriptación mediante el protocolo IPSec de la IETF, un método de encriptación robusto y muy difícil de comprometer.

Cuando se empezó a tomar conciencia de la fragilidad de la seguridad WiFi debido a las carencias del protocolo WEP, en algunos sectores se difundió el uso de VPN para reforzar la encriptación. A pesar de que WEP se puede utilizar de manera conjunta con VPN, es algo opcional, pues no añade seguridad adicional a IPSec.

A pesar de la seguridad añadida a las redes inalámbricas, este método tiene algunas ventajas. La principal es la económica, ya que cada túnel tiene un costo, por lo que en redes con una gran cantidad de usuarios las VPN se convierten en una solución extremadamente costosa. Otra gran desventaja es que las VPN han sido diseñadas para conexiones punto a punto y las Redes Wi-Fi transmiten ondas de Radio Frecuencia por un medio compartido, como es el aire. Las VPN protegen a partir de la capa 3 del modelo OSI, pero las Redes Wi-Fi funcionan en la capa 2.

En definitiva, esta es una medida de protección que fue utilizada durante un tiempo para solventar los problemas de seguridad del protocolo WEP, pero con la aparición de los nuevos protocolos WPA y WPA2 las VPN en Redes Wi-Fi cayeron en desuso.

2.10.2.8. Políticas de Seguridad

Sólo mediante tecnología no se puede garantizar un nivel de seguridad alto, ya que los usuarios de la Red Wi-Fi pueden comprometerla conectándose a Puntos de Acceso que no pertenecen a la red y facilitar información confidencial a extraños. Ataques de este tipo se verán a continuación, de la misma manera que se podrá comprobar la debilidad de la mayoría de medidas de seguridad que han sido descritas a lo largo de este capítulo. Por lo tanto, se hace necesario para completar un sistema de seguridad que existan ciertas políticas y guías de buenas prácticas, así como ciertos conocimientos sobre seguridad por parte de los usuarios.

El NIST, Nacional Institute of Standards and Technology, entre las principales recomendaciones que se incluyen en uno de sus documentos sobre la implementación de Redes Wi-Fi en las dependencias del gobierno de USA, hay una que aconseja desarrollar políticas de seguridad para wireless antes de comprar los equipos. Esta recomendación, en la práctica, casi nunca es llevada a cabo, la mayoría de organizaciones en primer lugar compran los dispositivos wireless y más tarde, cuando aparecen los problemas, deciden establecer políticas que regulen y controlen la utilización de las Redes Wi-Fi.

Las políticas que se deben establecer para la utilización de Redes Wi-Fi se deben referir básicamente al uso de los recursos Wi-Fi cuando los empleados se encuentran fuera de la organización, como podrán utilizar dichos recursos tanto los empleados de la organización como usuarios externos a la organización o el control de modificaciones en la topología de la red.

Como se puede comprender la rigurosidad en el uso de políticas dependerá de la importancia que se da a la información que se desea proteger.

Algunas de las políticas más relevantes que se aconsejan establecer en organizaciones son:

- Verificar que los usuarios están debidamente entrenados en el uso de tecnología Wi-Fi y conocen los riesgos asociados a su utilización.
- Cambiar el ESSID por defecto.
- Desactivar la opción de broadcast del ESSID, uso del método de protección CNAC.
- Verificar que en el ESSID no contiene datos de la organización que podrían ser utilizados por un atacante.
- Desarrollar una política de instalación de actualizaciones y parches en
- Puntos de Acceso y clientes de la red.
- Desarrollar una política de contraseñas para Puntos de Acceso y clientes.
- Desarrollar una política de configuración de los Puntos de Acceso.
- Desarrollar una política de autenticación de usuarios.
- Realizar auditorías periódicas sobre los Puntos de Acceso para comprobar que los parámetros de configuración no han sido modificados.
- Realizar auditorías periódicas sobre el Sistema de Seguridad de la Red.

Como se indicaba en el primer punto, es necesario que los usuarios de la red sepan cómo hacer un buen uso de las Redes Inalámbricas Wi-Fi. Con usuarios bien formados se podrán algunos de los ataques, que se describirán en el próximo apartado, como el Wi-Phishing y los problemas con Hotspots y Puntos de Acceso Hostiles.

La experiencia demuestra que gracias a una formación básica de los empleados en cuanto a la seguridad de sus sistemas se pueden reducir notablemente los riesgos que acechan a las Redes Wi-Fi. El proceso de formación de los empleados puede ser realizado en la misma empresa o enviando a los empleados que se desea formar a cursos externos. Lo importante es que dentro de la política de seguridad se asegure que los usuarios de la red disponen de los conocimientos necesarios para poder hacer un buen uso de la misma. Con esta rentable inversión se puede mejorar la seguridad incluso más que con el uso de herramientas tecnológicas.

2.10.3. Ataques sobre Redes Wi-Fi

2.10.3.1. Clasificación de los ataques

De forma genérica, podemos clasificar los ataques que pueden ser realizados sobre una Red Wi-Fi en 2 grandes categorías:

- **Ataques Pasivos**

Alguien no autorizado accede a la información, pero no realiza ninguna modificación de la misma. Dentro de esta categoría podemos mencionar dos tipos de actividades:

  - *Vigilar/Espiar.* El atacante monitorea el contenido de las transmisiones para descubrir el contenido de la información.
  - *Analizar el Tráfico.* El atacante captura la información transmitida y trata de descubrir datos sobre los parámetros de la comunicación, como el ESSID, contraseñas, Direcciones MAC o IP, etc.

- **Ataques Activos**

Alguien no autorizado modifica o altera el contenido de la información, o impide su utilización. En esta categoría existe un mayor número de actividades, pudiendo citar como las más comunes:

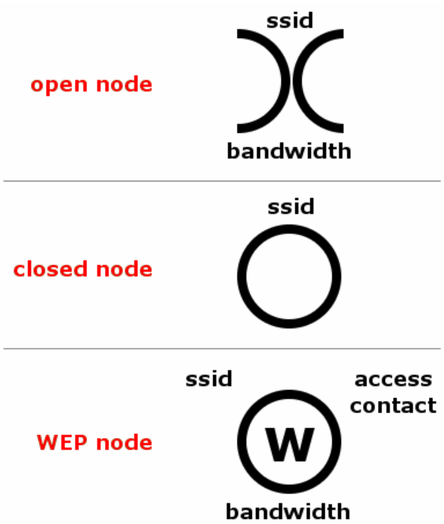
  - *Enmascaramiento.* Es un robo de identidad, en el que el “hacker” se hace pasar por un usuario autorizado para acceder a la información.

- *Retransmisión*. El atacante se coloca entre el emisor y el receptor, recibe la información y la retransmite, para evitar ser descubierto.
- *Alteración*. Basado en modificar mensajes legítimos añadiendo o borrando parte del contenido.
- *Denegación de Servicio*. El atacante impide la utilización normal de las transmisiones Wi-Fi. Con esta tecnología estos ataques son muy difíciles de evitar y muy fáciles de realizar.

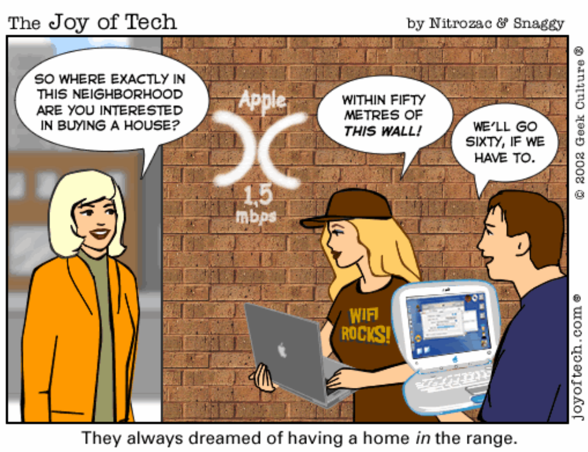
2.10.3.2. Warchalking y Wardriving

En los comienzos de Wi-Fi se generó una práctica en los países anglo-sajones que consistía en marcar unos símbolos con tiza donde se detectaban redes con esta tecnología, con la finalidad de que otros pudieran hacer uso de las mismas gratuitamente. A esta práctica se la conoce como Warchalking.

Dentro del Warchalking existe un lenguaje de símbolos para poder describir las características de la red existente, diferenciando entre redes abiertas o cerradas, el ESSID o nombre de la red, la tecnología utilizada, el ancho de banda, el tipo de cifrado, etc., como vemos en la imagen.



Fuente: http://www.warchalking.org



Fuente: http://www.joyoftech.com

De manera similar, se desarrolló el Wardriving, el método usado para la detección de redes inalámbricas, que consiste en recorrer una zona en un vehículo, o simplemente a pie, con un dispositivo como una PDA o un portátil, e ir señalando las redes inalámbricas protegidas y desprotegidas, habitualmente mediante una herramienta de software y utilizando una tarjeta Wi-Fi que permita entrar en modo monitor.

Adicionalmente se puede dotar al sistema de un GPS, con el que marcar exactamente en un mapa la posición de la red y trabajar de manera conjunta con la herramienta software que estamos utilizando.

Fuente: http://www.dust-dayz.com

Fuente: http://www.home-network-help.com

A primera vista este tipo de ataques pueden parecer inocentes, sin embargo, los riesgos a que se expone un sistema que permite el Warchalking y el Wardriving son enormes, a pesar de no hacer uso de información delicada, pues la seguridad será comprometida, corriendo el peligro de que su red pueda ser utilizada para enviar spam (Warspamming), para lanzar virus informáticos (Warvirusing), para hackear otras organizaciones, para crear redes de zombies, etc., además de lo que supone que se utilice nuestro ancho de banda.

2.10.3.3. DoS – Ataques de Denegación de Servicio

Existen multitud de herramientas para lanzar ataques sobre Redes Wi-Fi, en especial de Denegación de Servicio, DoS, que como ya comentamos son fáciles de llevar a cabo y extremadamente difíciles de poder detectar y evitar. Habitualmente son ataques que duran poco tiempo, lo que hace aumentar su dificultad de detección.

A continuación, se describen algunos de los ataques de Denegación de Servicio sobre Redes Wi-Fi más populares.

- **Saturación del Ambiente con Ruido de RF**

En el apartado 2.4.2. Calidad de la señal se comentaron las influencias negativas de las interferencias en las Redes Wireless, por lo tanto, un atacante puede producir ruido o interferencias deliberadamente que afecten a nuestra red, pues como se ha comentado durante todo el documento el medio de transmisión es público, provocando que la relación entre Señal y Ruido sea muy pequeña y nuestros usuarios pierdan la conectividad a la red. Es un ataque sencillo, y puede ser realizado con micro-ondas, o más profesionalmente con Generadores de Ruido. Si el administrador no cuenta con las herramientas apropiadas le resultará muy complicado detectar el ataque.

Fuente: http://www.promax.es

- **Torrente de Autenticaciones**

Este ataque se da en escenarios donde está implantado el estándar 802.1x y un Servidor RADIUS, donde es preciso que cada usuario se autentique. Este procedimiento es criptográficamente complejo y requiere un consumo considerable del procesador, pues se deberán implementar túneles y realizar búsquedas en bases de datos.

Si un atacante se dedicara a enviar falsas peticiones de autenticación repetitivas y en gran cantidad y, además, de manera simultánea, mantendría a la red ocupada con el complejo proceso de autenticación, con lo que lograría impedir que los usuarios legítimos pudieran autenticarse, pues el Servidor RADIUS estaría ocupado con el falso usuario.

- **WPA – Modificación de Paquetes**

Uno de los fallos importantes del protocolo WEP consiste en la falta de un método de chequeo de integridad. Los paquetes pueden ser alterados o sustraídos, sin que nadie se de cuenta. Una de las mejoras introducidas por WPA fue la inclusión de un sistema de chequeo de integridad (MIC), sin embargo, este sistema posee una vulnerabilidad que permite realizar ataques de Denegación de Servicio.

El citado mecanismo verifica si los paquetes han sido modificados o manipulados. Cuando detecta que en menos de un minuto se han modificado al menos dos paquetes el sistema asume que está siendo atacado y, como medida de prevención, desconecta a todos los usuarios de la red inalámbrica. Dicho esto resulta evidente cual será la metodología del ataque, el atacante alterará el contenido de varios paquetes, consiguiendo así la desconexión de todos los usuarios. Esta operación puede ser repetida constantemente provocando la pérdida de rendimiento en la red.

- **Desautenticación de Clientes**

El ataque descrito anteriormente provocaba la desautenticación de todos los usuarios de la red por mensajes enviados por el AP. Por lo tanto, disponiendo de las direcciones MAC necesarias, la del AP y la de los clientes asociados, podremos falsificar y crear paquetes de Desauthentication como los que enviaba el AP para desautenticar a estaciones en concreto o, de la misma manera que el método anterior, a todos los clientes de la red, haciéndonos pasar por el AP.

2.10.3.4. Falsificación de Identidades

Los ataques que van a ser descritos a continuación se basan en el engaño y suplantación de identidades o dispositivos que pertenecen a la Red Wi-Fi objetivo. Las posibilidades serán hacer creer al AP que el atacante es un usuario legítimo o hacer creer a los clientes que el atacante es el AP al que se deben asociar.

- **Rogue Access Points – Honeypots**

La existencia de Rogue Access Points, Puntos de Acceso Hostiles, son un tema difícil de solucionar en Seguridad Wi-Fi. Son conexiones que se establecen voluntaria o involuntariamente y, por su naturaleza son temporales. El problema consiste en que hay que detectarlas en el momento, mientras está sucediendo.

Así como nosotros tenemos nuestros Puntos de Acceso, es muy probable, que vecinos o empresas próximas tengan los suyos. Esto supone una amenaza constante a nuestra red y a nuestros dispositivos Wi-Fi, que además es inevitable, pues no se puede prohibir a un vecino que instale su propia Red Wireless, por lo tanto, es un peligro con el que se debe convivir.

La definición de un Punto de Acceso Hostil es, por tanto, todo Punto de Acceso que no ha sido instalado y autorizado por el administrador de nuestra de red, existiendo, básicamente, 3 fuentes: vecinos, insiders (miembros de nuestra red, visitantes, etc.) y hackers.

Básicamente el objetivo del atacante que utiliza un Punto de Acceso Hostil es conseguir información sobre nuestra red, para posteriormente conseguir la información que circula en nuestro sistema.

La forma de protegerse frente a este peligro es detectar y localizar los Puntos de Acceso que no pertenecen a nuestra red para, en primer lugar, prevenir. Si se detecta el Punto de Acceso es hostil deberemos tratar de eliminarlo si es posible, o si no es posible, bloquear el acceso a dicho AP por parte de los clientes de nuestra red.

Un problema más difícil de detectar es cuando se trata con un Punto de Acceso Honeypot. Este ataque consiste en utilizar un AP pirata con el mismo ESSID al que se conecta un cliente y una señal fuerte para conseguir que algún usuario se asocie enviando su login y/o contraseña, con la que posteriormente el atacante tendrá acceso a la red.

Una forma de utilizar los Honeypots es en redes donde se realiza roaming. De esta forma será más sencillo que un cliente que detecte una mejor calidad de señal se desasocie del Punto de Acceso legítimo y se asocie al falso.

- **Wi-Phishing**

Los Hotspots, antes mencionados, son Puntos de Acceso Wi-Fi públicos, el principal problema de este tipo de APs es que suelen utilizar mecanismos de seguridad muy débiles, ya que los proveedores del servicio no tienen especial interés en proteger la información que circula en sus redes, habitualmente sólo se encuentra implementada seguridad a nivel de acceso. Por esto, es el usuario el que deberá velar por la seguridad de su información, algo que un usuario medio no sabrá como hacer.

Uno de los ataques más populares sobre este tipo de redes es el Wi-Phishing. Un usuario cuando desea conectarse a Internet desde un sitio público debe, en primer lugar, comprobar los Puntos de Acceso que le ofrecen conexión, algo nada fácil. Un atacante, utilizando ingeniería social, puede colocar un AP con un ESSID que transmita confianza a los posibles clientes víctima.

Una vez un usuario decide conectarse al AP, colocado por el atacante, toda la información que se transmita por la red podrá ser fácilmente comprometida. Muchos Puntos de Acceso públicos poseen un menú de bienvenida, habitualmente este tipo de redes son utilizadas eventualmente por los usuarios, por lo que se suele desconocer cual debe ser el aspecto auténtico de este menú.

Antes de permitir la conexión puede que el atacante, mediante el menú, intente obtener algún tipo de información confidencial que sea facilitada por los usuarios más confiados, como contraseñas, números de identidad, cuentas bancarias, números de tarjetas de crédito, etc.

Todo lo dicho se refiere a la información que el atacante puede robar mientras permanece activa la conexión al Punto de Acceso, pero un atacante con más paciencia y que no desee bombardear al usuario con solicitudes de información confidencial, algo que podría hacerle desconfiar, puede introducir en la máquina del usuario malware de tipo virus, spyware, troyanos o keyloggers, con los que podría acabar obteniendo la misma información en momentos donde el usuario se sintiese más confiado.

Un tipo de ataque similar al Wi-Phishing, pero más ambicioso en cuanto a su alcance, es el Evil Twin. La metodología de acceso o engaño a la víctima es similar, pero se busca conseguir más datos. El Evil Twin, es en realidad, un ataque Man In The Middle que redirige al usuario a páginas web peligrosas, donde es atacado por malware. Existen páginas donde con tan sólo mover el ratón se descarga spyware.

- **MAC Address Spoofing**

Este ataque se realizará cuando la red objetivo está protegida mediante un mecanismo de Filtrado de Direcciones MAC. Ya se comentó que éste era un método de seguridad poco efectivo, que autenticaba a dispositivos y no a usuarios.

Para realizar el ataque simplemente detectando alguna dirección MAC que se encuentra asociada al AP, ésta podrá ser utilizada suplantando a la MAC original de la Tarjeta de Red Wi-Fi del atacante. Dado que las direcciones MAC se envían en claro, el proceso de detección resultará muy sencillo, una vez se falsifique la dirección MAC, el AP permitirá el acceso a la red al atacante.

- **MITM – Man In The Middle**

El atacante con este método consigue ubicarse entre el AP y el dispositivo Wi- Fi cliente, de esta manera consigue controlar la comunicación entre el cliente y el AP. Realizando este tipo de ataque el hacker podrá modificar o alterar la información que se está transmitiendo a través suyo, con el fin de engañar al receptor, transmitir la información sin ningún cambio, de manera que nadie se de cuenta de su presencia y pueda conocer el contenido de la conversación, o bloquear la transmisión de manera que la información nunca llegue al receptor.

Para llevar a cabo este ataque, en primer lugar, se deberá localizar la red objetivo y conseguir información sobre la misma, tanto del Punto de Acceso como de los clientes. Además se necesitará un Punto de Acceso Wi-Fi que suplantará al AP original y una estación con una Tarjeta de Red Wi-Fi que suplantará al cliente objetivo. Existe software que emula Puntos de Acceso en un PC, lo que resultaría suficiente para realizar el ataque si se dispone de un tarjeta de red.

Una vez está todo dispuesto, el atacante deberá conseguir que el cliente objetivo se asocie a su Punto de Acceso pensando que es el auténtico y, además, asociarse al AP original con el cliente falso. Una vez conseguido esto, el atacante podrá participar en las actividades de la Red Wi-Fi pues ante el Punto de Acceso será un cliente legítimo.

- **Session Hijacking**

El ataque de “Secuestro de Sesión”, esta basado en desautenticar a un usuario que está asociado a la red y reemplazarlo.

El modo de operación, como en todos los ataques, comienza detectando y seleccionado la red objetivo y monitorizándola para obtener información como ESSID, direcciones MAC, etc. A continuación se realiza un ataque de Denegación de Servicio contra el cliente seleccionado para ser suplantado, consiguiendo así que sea desautenticado.

Con la información que había obtenido, el atacante procede a conectarse a la red en reemplazo del usuario expulsado, suplantándolo. El usuario legítimo intentará conectarse, pero el AP no se lo permitirá, pues ya existirá un cliente con sus características conectado. Evidentemente este ataque se realizará cuando el Punto de Acceso utiliza mecanismos o listas de autenticación.

Una vez conectado, el atacante debe actuar rápidamente para evitar sospechas, pues el cliente al notar que no se puede conectar a la red notará que algo no va bien, pudiendo dejar un backdoor en el sistema de seguridad de la red para poder volver a acceder posteriormente. Una vez hecho esto el atacante se deberá retirar permitiendo al cliente volver a conectarse.

Si el tiempo que el atacante quiere dejar desconectado al usuario auténtico de la red no es suficiente para completar posteriores ataques, que requieren que esté asociado a la red, podrá repetir el proceso de suplantación sobre otros clientes evitando así sospechas.

Al ser un ataque que habitualmente dura muy poco tiempo, resulta muy complicado para el administrador de la red detectar el ataque, sobretodo si no se cuenta con herramientas específicas como los ya comentados Switches WLAN.

2.10.3.6. Ataques de Intrusión

Ataques que ya hemos visto como los de Falsificación de Identidades podrían también ser clasificados como Ataques de Intrusión, pero en esta categoría se describirán ataques, que como se verá, explotan otro tipo de vulnerabilidades.

- **Romper claves WEP**

Ya se ha explicado, en las medidas de seguridad, el protocolo de cifrado WEP con sus principales características: su popularidad y su debilidad. Partiendo de que la seguridad de este protocolo puede romperse mediante un ataque de fuerza bruta, es decir, probando todas las combinaciones posibles hasta descubrir la clave, en este apartado se describirá un ataque mucho más rápido y efectivo

Como ya se comentó WEP se basa en el cifrado RC4 para codificar la información con la clave de red. Esta clave suele estar formada por un total de 64 o 128 bits, siendo la parte fundamental el Vector de Inicialización, 24 bits semialeatorios, que son transmitidos en texto plano.

Una vez se ha seleccionado la red y el Punto de Acceso sobre el que se va a realizar el ataque, se debe capturar el tráfico que se transmite sobre dicha red. Debido a que el tráfico habitualmente es muy bajo, el atacante puede hacer que éste aumenté realizando otros ataques de manera conjunta, provocando desautenticaciones de los clientes y/o inyectando tráfico en la red que provoque la generación de nuevos IVs, como la inyección de peticiones ARP.

Una vez se ha capturado tráfico suficiente comienza el proceso de *"cracking"* de la contraseña utilizando la captura realizada, con lo que se obtendrá la clave WEP.

- **Romper claves WPA**

Este tipo de ataques es muy semejante a los ataques para romper claves WEP, sin embargo las diferencias entre estos protocolos hace que la metodología de ataque sea un poco distinta.

Una de las principales diferencias a la hora de realizar este ataque es que no importa tanto la cantidad de tráfico capturado como ocurría en los ataques sobre claves WEP, lo realmente importante es capturar un tipo de tráfico concreto generado en el momento de autenticación del cliente conocido como "*handshake"*.

Por lo tanto el comienzo del ataque será igual que en el caso anterior, seleccionando la red, capturando tráfico y realizando simplemente un ataque de Denegación de Servicio sobre un cliente, ya que con solamente un handshake será posible descifrar la clave. Adicionalmente será necesario disponer de un diccionario que compare sus valores con dicho paquete.

Debido a que la clave será descubierta sólo en función de que exista la misma en una entrada del diccionario, la elección y la calidad del mismo es fundamental para el éxito del ataque.

- **Ataque a Cisco EAP – LEAP**

La vulnerabilidad sobre el método de autenticación EAP – LEAP desarrollado por Cisco y la metodología para lanzar un ataque off-line fueron presentadas en
2003.

Todo algoritmo basado en claves o contraseñas puede ser atacado con la finalidad de descubrir la contraseña de acceso. En este caso se realiza un ataque de diccionario, es decir, utilizando un listado de palabras clave.

Existen herramientas que automatizan y facilitan la realización de ataques de diccionario sobre Redes Wi-Fi protegidas con el método de autenticación EAP-LEAP. Como este ataque puede ser realizado off-line, es posible capturar una cantidad de tráfico determinada y luego atacarla hasta descubrir la contraseña.

- **Explotando APs mal configurados**

El encontrarse con un Punto de Acceso mal configurado es algo habitual, esto facilita enormemente la tarea de intrusión en una Red Wi-Fi.

Todos los APs poseen características predeterminadas con las que salen configurados de fábrica. En algunos casos se protegen con contraseña y otros directamente no poseen ninguna, lo mismo ocurre con el ESSID. Estos datos son conocidos por muchísimas personas, pueden ser consultados en Internet, y deben ser cambiados en el momento de la instalación.

2.11. Magnitudes estudiadas

Para poder obtener unos resultados significativos, que mostrasen el estado y funcionamiento de la red Wi-Fi de la Universidad de Extremadura, hemos estudiado los siguientes parámetros que son definidos a continuación.

2.11.1. Señal Ruido

La relación señal/ruido (en inglés Signal to Noise ratio SNR o S/N) se define como la proporción existente entre la potencia de la señal que se transmite y la potencia del ruido que la corrompe. Este margen es medido en decibelios.

Este parámetro indica la diferencia mínima entre la potencia de señal y de ruido que el receptor puede soportar para funcionar correctamente, es decir, aunque tengamos mucha potencia de señal, si el ruido también es muy alto, nuestro receptor no será capaz de distinguir lo que es señal útil del ruido y no funcionará.

Se entiende como ruido cualquier señal no deseada, en este caso señal eléctrica no deseada que circula por el interior de un equipo electrónico. El ruido se mide sin ninguna señal a la entrada del equipo.

Sin embargo, si quieres determinar la precisión de las herramientas de tu red Wi-Fi, necesitarás un generador consistente de señal que proveerá una cantidad definida de ruido.

Interpretación de los valores

- **10dB o menos:** es muy malo y se podrían experimentar falta de sincronismo o problemas intermitentes de sincronismo.
- **10dB a 20dB:** es posible la conexión, pero no deja mucho espacio para variaciones de las condiciones y la velocidad de transmisión se puede ver afectada.
- **20dB a 30dB:** es bueno con pocos o ningún problema de sincronismo.
- **30dB a 40dB:** es excelente.
- **40dB o por encima:** es extraordinario.

Esta escala se aplica a algunos dispositivos. Según el tipo de modulación y receptor el valor saldrá indicado de esta manera o de otra similar. No siempre es una escala logarítmica. El fabricante es el que indica que significa la escala. (si son dbm dbuV...) y en función de la modulación se saben los márgenes aceptables.

2.11.2. Nivel de Señal

El indicador de fuerza de la señal recibida (RSSI por las siglas del inglés *Received Signal Strength Indicator*), es una escala de referencia (en relación a 1 mW) para medir el nivel de potencia de las señales recibidas por un dispositivo en las redes inalámbricas (típicamente WIFI o telefonía móvil). La escala tiene al valor 0 (cero) como centro; representa *0 RSSI*, o *0 dBm*. Aunque teóricamente puede darse el caso de medirse valores positivos, generalmente la escala se expresa dentro de valores negativos; cuanto más negativo, mayor pérdida de señal.

El RSSI indica intensidad recibida, no calidad de señal, ya que ésta última se determina contrastando la intensidad de la señal respecto de la relación señal/ruido (Eb/No).
Nota: En esta escala, un nivel de 0 dBm es igual a 1 mW (milivatio).

Interpretación de los valores

En una escala de 0 a -80 dBm:

- **0**: señal ideal, difícil de lograr en la práctica.
- **-40 a -60**: señal idónea con tasas de transferencia estables.
- **-60**: enlace bueno; ajustando TX y basic rates se puede lograr una conexión estable al 80%.
- **-70**: enlace normal -bajo; es una señal medianamente buena, aunque se pueden sufrir problemas con lluvia y viento.
- **-80**: es la señal mínima aceptable para establecer la conexión; puede ocurrir caídas, que se traducen en corte de comunicación (pérdida de llamada, perdida de datos, mensajes (SMS) corruptos (ilegibles).

Esta escala se aplica a algunos dispositivos. Según el tipo de modulación y receptor el valor saldrá indicado de esta manera o de otra similar. No siempre es una escala logarítmica. El fabricante es el que indica que significa la escala. (si son dbm dbuV...) y en función de la modulación se saben los márgenes aceptables.

2.11.3. Cantidad de puntos de acceso

Mediante los mapas de calor creados en torno a esto, podremos observar el número de redes que estarán disponibles desde los distintos puntos de las zonas estudiadas.

A mayor número de redes, mejor dato, puesto que en el caso de que alguna no estuviese disponible por un determinado periodo de tiempo se podría realizar la conexión a otra.

Tomaremos como referencia para tener en cuenta una conexión en una zona en la que se reciba una señal cuyo valor mínimo de nivel sea de -80dBm, a su vez que sólo se mostrarán los puntos de acceso próximos en los que obtengamos un valor mínimo de -60 dBm.

2.11.4. Cobertura por Banda de Frecuencia

Muchos de los problemas que podemos tener (saturación, errores, lentitud, alcance limitado) podríamos solucionarlos con un router Wi-Fi de banda dual (también llamados de doble banda o dual-band) como los que se utilizan en la Universidad de Extremadura.

El problema de los 2,4 GHz

Los routers básicos suelen emitir únicamente en la banda de 2,4 GHz, ya sea Wi-Fi 802.11b, 802.11g o 802.11n. Las ondas emitidas en esta zona del espectro de frecuencias reciben el nombre de microondas y en nuestro país disponemos de trece canales para elegir.

No obstante, esa banda es utilizada por más tecnologías: emisores/receptores de teclados y ratones inalámbricos, teléfonos inalámbricos, Bluetooth. Además tiende a ser interferida por otros electrodomésticos (microondas).

Una red puede interferir con aquellas que se encuentran hasta a cuatro canales de distancia del suyo. La banda cercana a los 2,4 GHz está, en definitiva, muy saturada, sobre todo en zonas urbanas. Un router dual-band puede aportarnos algunas ventajas bastante interesantes.

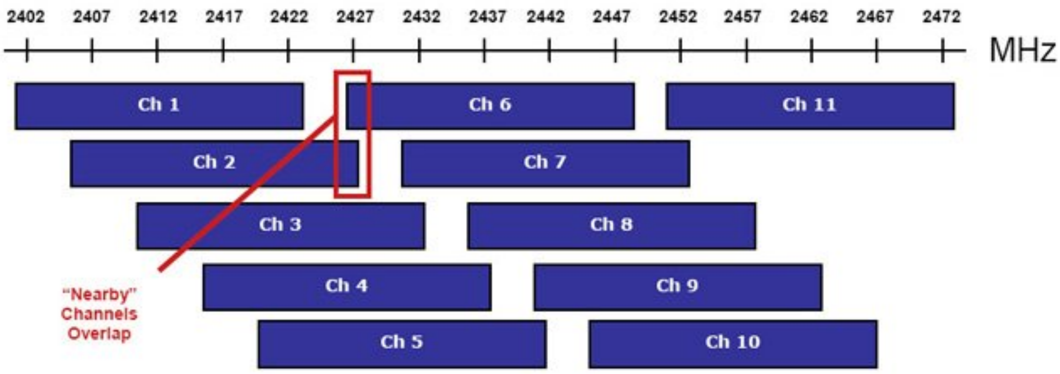
Ventajas de un router de banda dual

Un router dual-band emite simultáneamente señales en la banda de los 2,4GHz y en la de los 5 GHz, con menor cantidad de redes presentes.
La banda de los 5GHz está menos congestionada, lo que reduce las hipotéticas interferencias y ruidos, además de permitir alcanzar mayores velocidades mediante el uso simultáneo de varios canales, ofreciendo un mayor rendimiento.

La contrapartida de funcionar sobre 5 GHz es que no tenemos tanto alcance como en 2,4GHz en espacio abierto o a la hora de atravesar paredes, techos, etc., con lo que la cobertura se ve limitada.

Cuando se definió el estándar IEEE 802.11 (el que regula las redes locales inalámbricas), se especificó también los tres rangos de frecuencia disponibles para los dispositivos que desearan emitir de esta forma: 2.4GHz, 3.6 GHz y 5 GHz.

Para 2.4 GHz, existen 14 canales, separados por 5 MHz. Cada país y zona geográfica aplica sus propias restricciones al número de canales disponibles. Por ejemplo, en Norteamérica tan sólo se utilizan los 11 primeros, mientras que en Europa se dispone de 13. El problema de esta distribución es que cada canal necesita 22MHz de ancho de banda para operar, y como se puede apreciar en la figura esto produce un solapamiento de varios canales contiguos.



Con los routers de banda dual conseguimos lo mejor de ambos mundos. Es decir, tenemos la cobertura más amplia de 2,4 GHz y la mayor velocidad y menor saturación de 5 GHz.

Como resumen a lo mencionado anteriormente podemos realizar una clasificación de las cualidades que nos ofrece el trabajar con distintas frecuencias.

Puntos fuertes de la banda de 2.4GHz

- Mayor cobertura debido a que la atenuación en el aire es menor que la banda de 5GHz.
- Velocidad de hasta 450Mbps con el uso de la tecnología Three-Stream y la configuración MIMO 3T3R (3 antenas de emisión, 3 antenas de recepción) de los routers.
- Compatibilidad con todos los dispositivos Wi-Fi que hay actualmente como tablets, smartphones, consolas, portátiles etc. La banda de 2.4GHz lleva con nosotros mucho tiempo y asegura compatibilidad con productos 802.11b/g/n.
- Los enlaces a larga distancia, es recomendable hacerlo en la banda de 2.4GHz si el espectro no está saturado porque llegaremos más lejos (menor atenuación en el aire).

Puntos débiles de la banda de 2.4GHz.

- El espectro está muy saturado así que si vivimos en pisos, es posible que tengamos interferencias con otras redes Wi-Fi y no consigamos un buen rendimiento. Las interferencias también afectarán a la cobertura inalámbrica.
- No podremos conseguir más velocidad de 450Mbps.
- La mayoría de fabricantes han optado por incorporar la característica HT20/40 Coexistence.
- Debido al HT20/40 Coexistence, casi siempre tendremos un ancho de canal de 20MHz en lugar de 40MHz por lo que el rendimiento (en cuanto a velocidad de transferencia se refiere) se verá afectado negativamente.

3. METODOLOGÍA.

3. METODOLOGÍA.

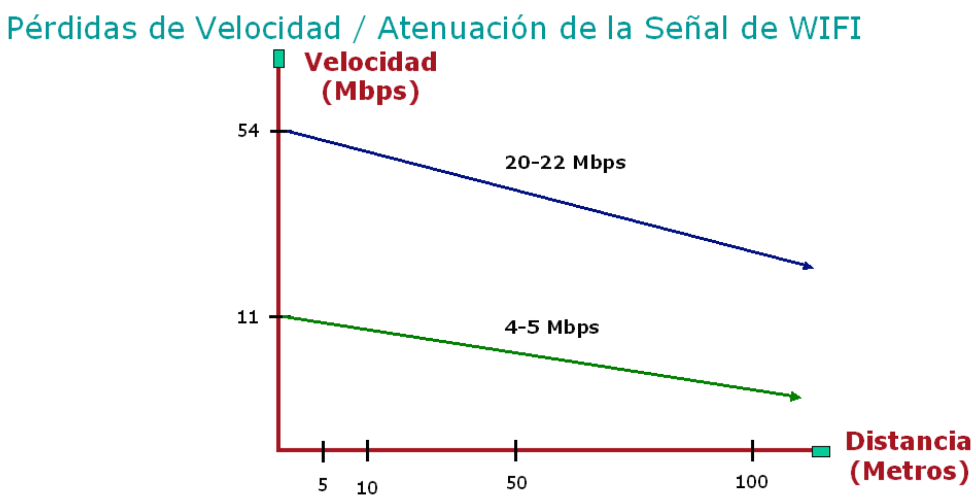
En este capítulo se detalla el procedimiento utilizado para poder alcanzar los objetivos propuesto a la hora de iniciar este proyecto. Así mismo, se definen las especificaciones técnicas de los equipos de medida utilizados.

3.1. Mediciones

La recogida de datos se ha llevado a cabo recorriendo el total de las zonas estudiadas, realizando medidas cada aproximadamente 5 metros siempre que fuese posible, teniendo en cuenta paredes y otras barreras arquitectónicas, también se han considerado algunas particularidades de ciertos espacios, como instrumentos o dispositivos que pudiesen interferir en los resultados.

3.1.1. Atenuación

A la hora de realizar las mediciones se ha tenido en cuenta la atenuación que se producía tanto por la distancia como por los obstáculos. A continuación podremos observar la importancia de estos factores a la hora de una buena comunicación inalámbrica. En primer lugar, en la siguiente imagen podemos observar como influye la distancia en el rendimiento de una red inalámbrica.



De igual forma que la distancia, los obstáculos entre los dispositivos influyen, pudiendo reflejar o absorber la señal, provocando su degradación e incluso bloquearla. Los obstáculos más habituales que nos hemos podido encontrar son los siguientes:

• Paredes

Son un obstáculo obvio, debiendo evitar en lo posible el número de paredes a cruzar. Pero la composición de la pared es también relevante. El yeso atenúa pero no bloquea la señal, sin embargo materiales de construcción más pesados, tales como muros de hormigón, pueden llegar incluso a anular totalmente una señal.

• Armarios

Al igual que las paredes, los armarios también atenúan la señal. Es importante tener en cuenta el tipo de material de estos armarios, que pueden llegar a eliminar completamente la señal si son de materiales metálicos.

• Azulejos

Pueden tener un efecto bastante atenuador en la intensidad de la señal.

• Elementos naturales

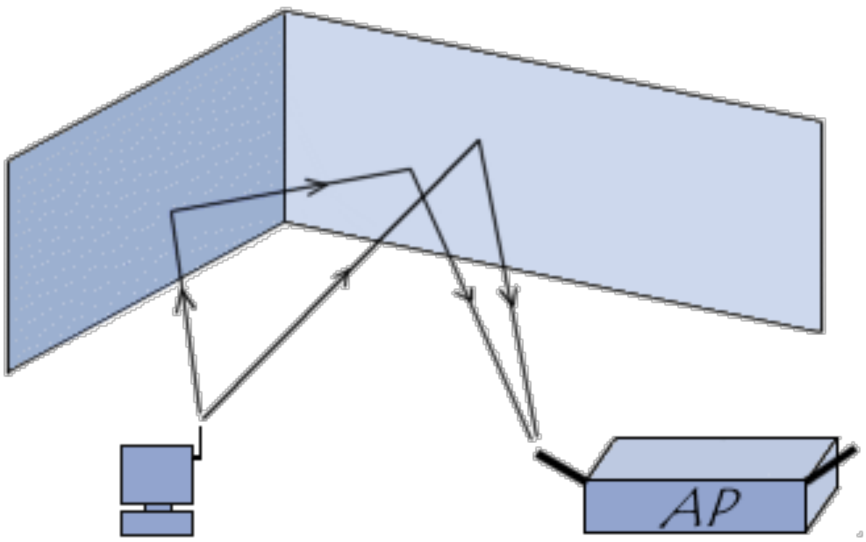
Elementos como agua, árboles y arbustos, que pueden encontrarse en un jardín o patio, también degradan la señal.

• Cristal revestido

El cristal transparente normalmente no degrada la señal. Sin embargo, puede tener un efecto perjudicial si es un cristal cubierto con una película metalizada o tiene un acoplamiento de alambre encajado en él, como puede ser un espejo, una vidriera, el cristal de un ascensor, etc.

• Reflexión

Algunos objetos como pueden ser las paredes, no absorben la señal sino que la reflejan como un espejo refleja la luz. En estos casos, la reflexión se puede explotar como manera de extender una señal o de doblarla alrededor de un pasillo. En la siguiente imagen se muestra como se produciría este efecto.



• Techos

Si la casa dispone de una instalación de falso techo o altillo, se podría pensar en situar ahí el router inalámbrico y de esta manera tenerlo oculto. En este caso, es importante tener en cuenta:

- El material del techo y del altillo, si está recubierto de un material que pueda atenuar la señal.
- Se está ofreciendo cobertura al piso de arriba, por lo que es importante cuidar las medidas de seguridad de la red creada.
- Cómo localizar la conexión eléctrica para situar el router inalámbrico.

Por último, se muestra una tabla donde se pueden observar como afectan a la señal dependiendo del material del que están fabricados y donde los podemos encontrar.

Material	Grado de Atenuación	Ejemplo
Espacio abierto	Ninguno	Cafetería, patio
Madera	Bajo	Pared interna, partición de la oficina, puertos, suelo
Escayola	Bajo	Paredes internas
Materiales sintéticos	Bajo	Tabiques o mamparas de oficina
Amianto	Bajo	Techos
Cristal	Bajo	Ventana
Acoplamiento de alambre en cristal	Medio	Puerta, particiones
Cristal tintado con metal	Bajo	Ventanas tintadas
Cuerpo humano	Medio	Grupo grande de personas
Agua	Medio	Madera húmeda, acuario, inventario orgánico
Ladrillos	Medio	Pared interna, pared externa, piso
Mármol	Medio	Pared interna, pared externa, piso
Cerámica (con contenido de metal)	Alto	Baldosa cerámica, techo, suelo
Papel	Alto	Rodillo o grandes capas de papel
Hormigón	Alto	Suelo, paredes externas, pilares, columnas
Cristal a prueba de balas	Alto	Cabina de seguridad
Plateado	Muy alto	Espejos
Metal	Muy alto	Escritorios, mamparas de oficina, refuerzos de hormigón, hueco del ascensor, armario de archivos, sistemas de aspersión, ventiladores

3.2. Software

NetSpot es una herramienta de software para redes inalámbricas, mediante la que se puede realizar el análisis de estas, proporcionando datos de la cobertura y el rendimiento de redes Wi-Fi. Se ejecuta en Mac OS X y es compatible con 802.11n, 802.11a, 802.11b, y 802.11g.

NetSpot utiliza el adaptador de red Wi-Fi estándar y la interfaz Airport para elaborar un mapa de cobertura y analizar otros parámetros de la red inalámbrica y crear informes detallados.

3.2.1. Funciones

NetSpot proporciona datos visuales para ayudar a analizar las pérdidas de señal, descubrir las fuentes de ruido, el uso de canales, optimizar los puntos de acceso locales. Además, la aplicación es capaz de realizar la planificación de redes Wi-Fi: los datos que se recogen ayuda para seleccionar los canales y las ubicaciones de los nuevos puntos de acceso Wi-Fi. NetSpot puede generar informes en formato PDF.

3.3. Equipos

3.3.1. Puntos de Acceso

Encontramos dos modelos de equipos en la red inalámbrica de la Universidad de Extremadura, los cuales se definirán a continuación, junto a sus características técnicas.

Ficha técnica

CARACTERÍSTICAS ELÉCTRICAS DEL ROUTER HP MSM 460	
Ganancia de la antena de 2,4 GHz	5 dBi
Ganancia de la antena de 5 GHz	7 dBi
Protocolo de interconexión de datos	IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11n.
Temperatura operacional	0º a 40º C

CARACTERÍSTICAS ELÉCTRICAS DEL ROUTER 3COM 8760	
Ganancia de la antena de 2,4 GHz	4 dBi
Ganancia de la antena de 5 GHz	6 dBi
Protocolo de interconexión de datos	IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11 Super AG
Temperatura operacional	-10º a 40º C

3.3.2 Equipo de medición

El equipo utilizado para realizar las mediciones Macbook Air.

La tarjeta inalámbrica de red es una AirPort Extreme (0x14E4, 0xE9) con firmware Broadcom BCM43xx 1.0 (5.106.98.100.22) cuyas características se definen a continuación.

CARACTERÍSTICAS ELÉCTRICAS DE LA TARJETA INALÁMBRICA AIRPORT EXTREME (0x14E4, 0xE9)	
Potencia de salida típica	15 dBm
Sensibilidad mínima	-82 dBm a 11 Mbps
Protocolo de interconexión de datos	IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11n
Temperatura operacional	0º a 40º C

4. RESULTADOS Y DISCUSIÓN

Measurements were taken in the different buildings of the University of Extremadura, following the methodology explained above. A detailed explanation of the results obtained in the different areas is presented below.

Heat maps are used to represent in a more visual way the information obtained.

4. RESULTS AND DISCUSSION

Heat Maps Keys

Signal to Noise Ratio

Signal Level

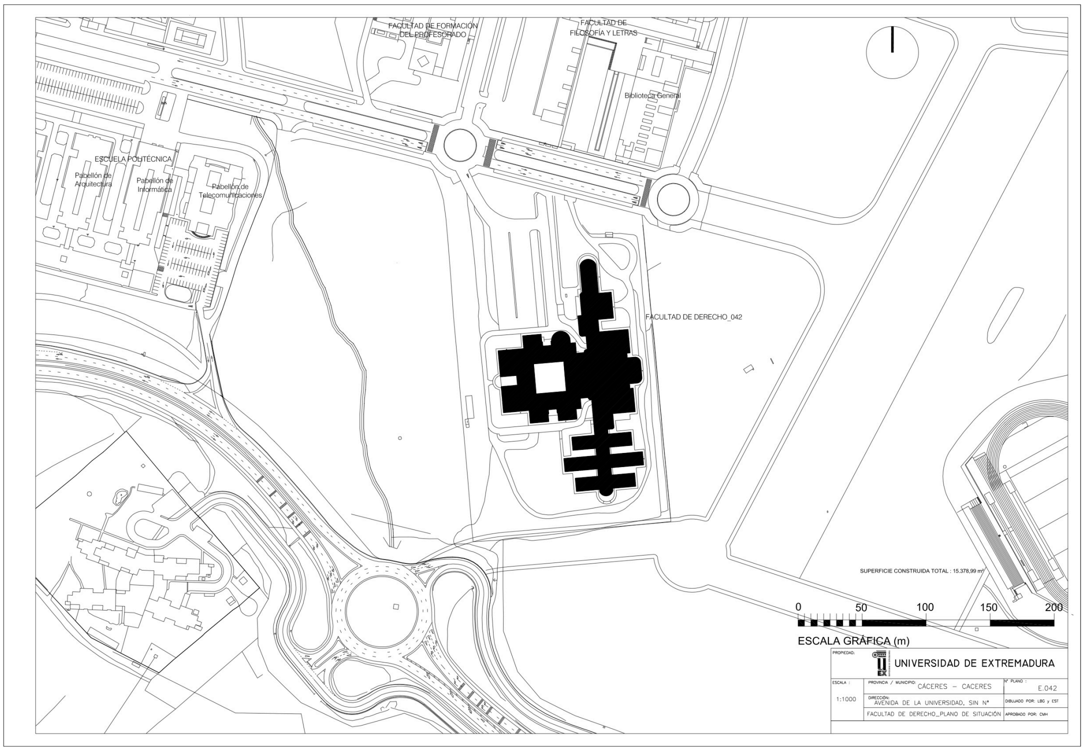
Number of Access points

Coverage per frequency band

4.1. Facultad de Derecho

A total of 433 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

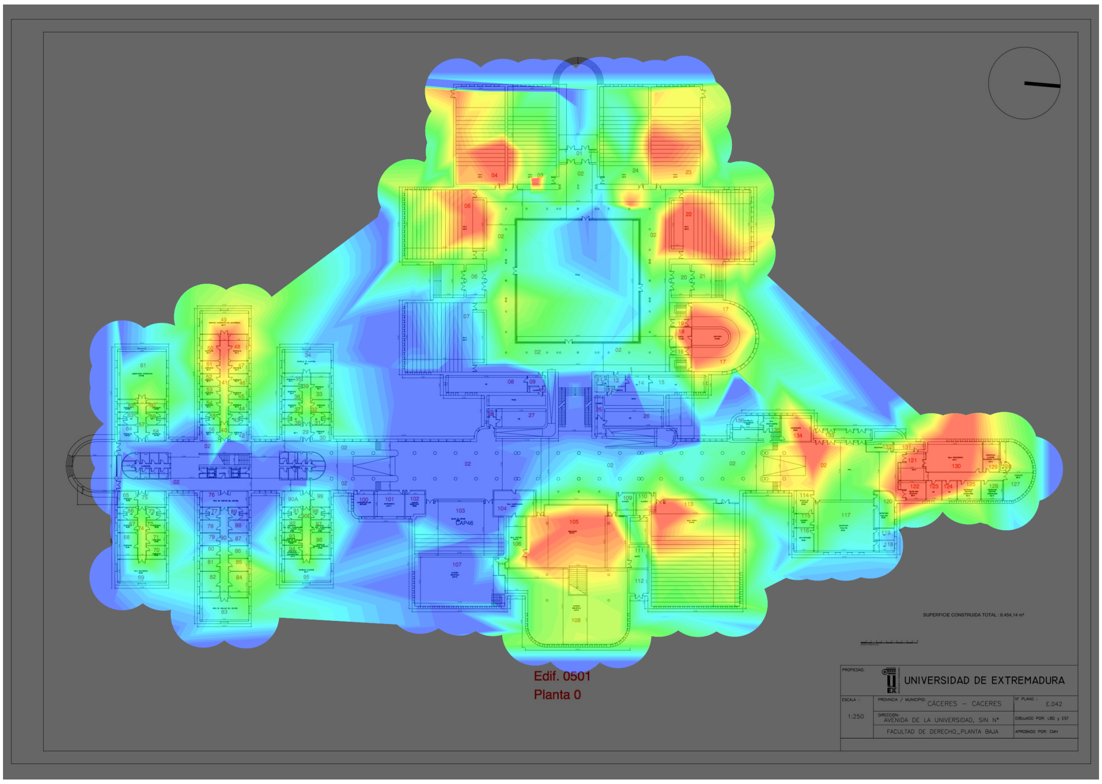
We see the location of the Faculty of Law on the following plan.



4.1.1. Building 0501 Floor 0

4.1.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

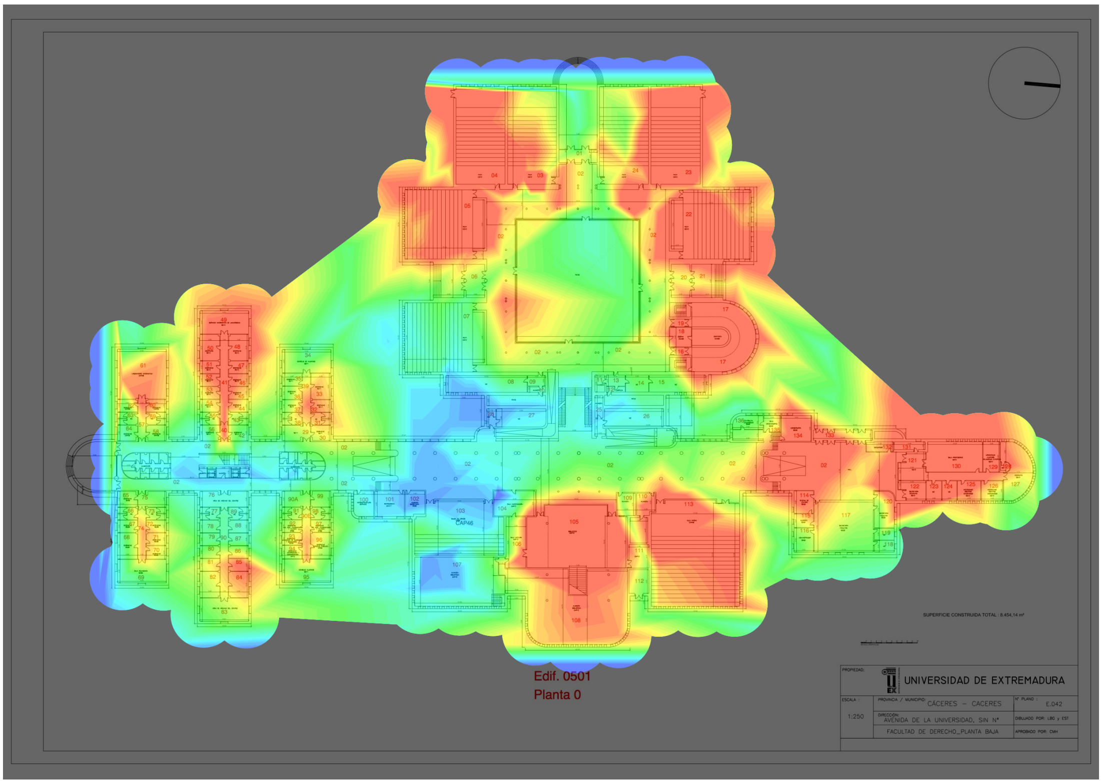


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.1.1.2. Signal Level



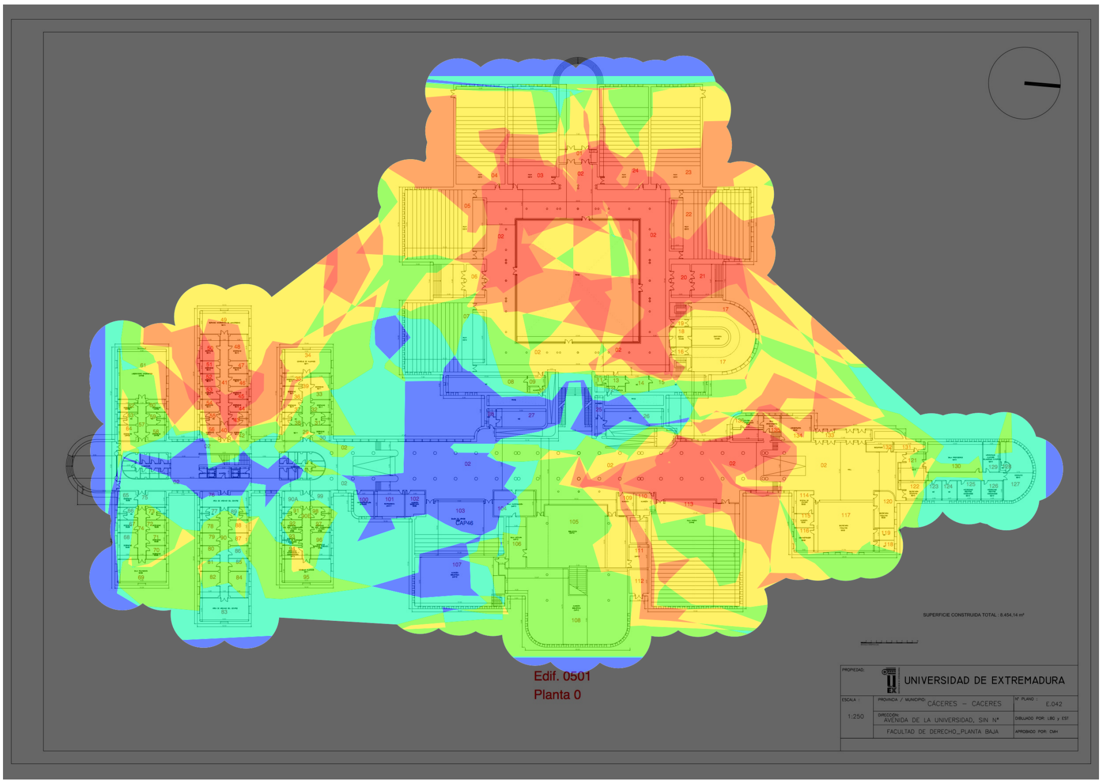
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.1.1.3. Number of Access Points

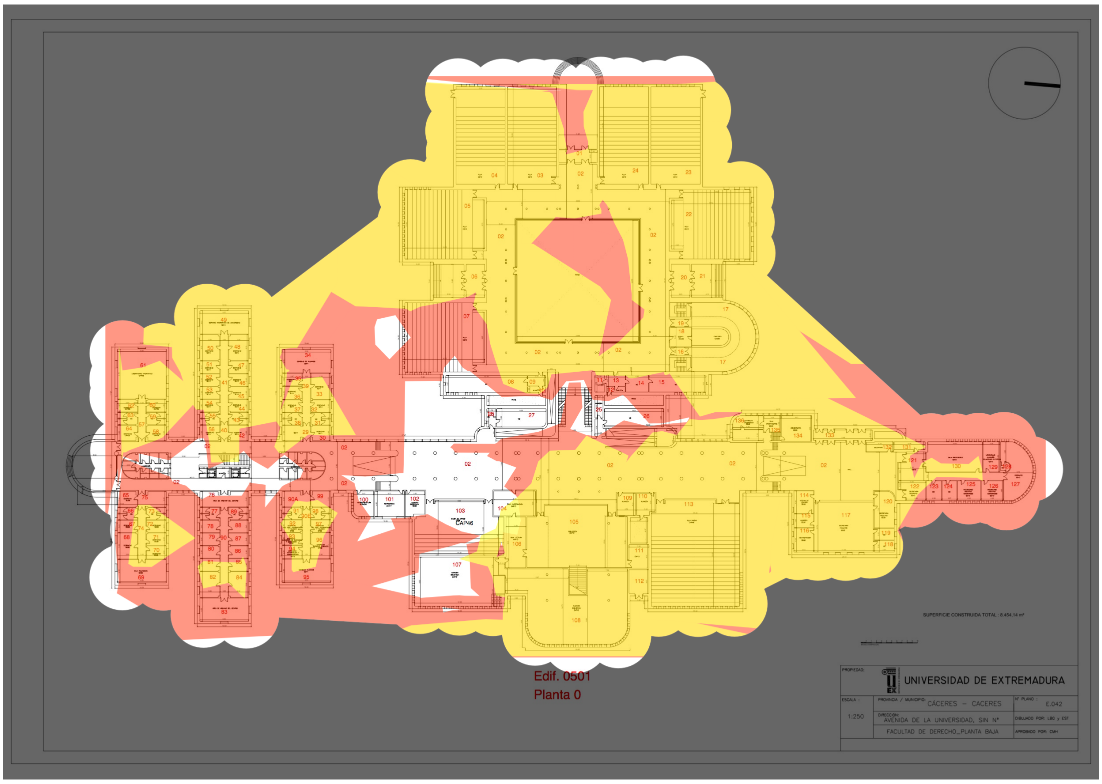


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.1.1.4. Coverage per Frequency Band



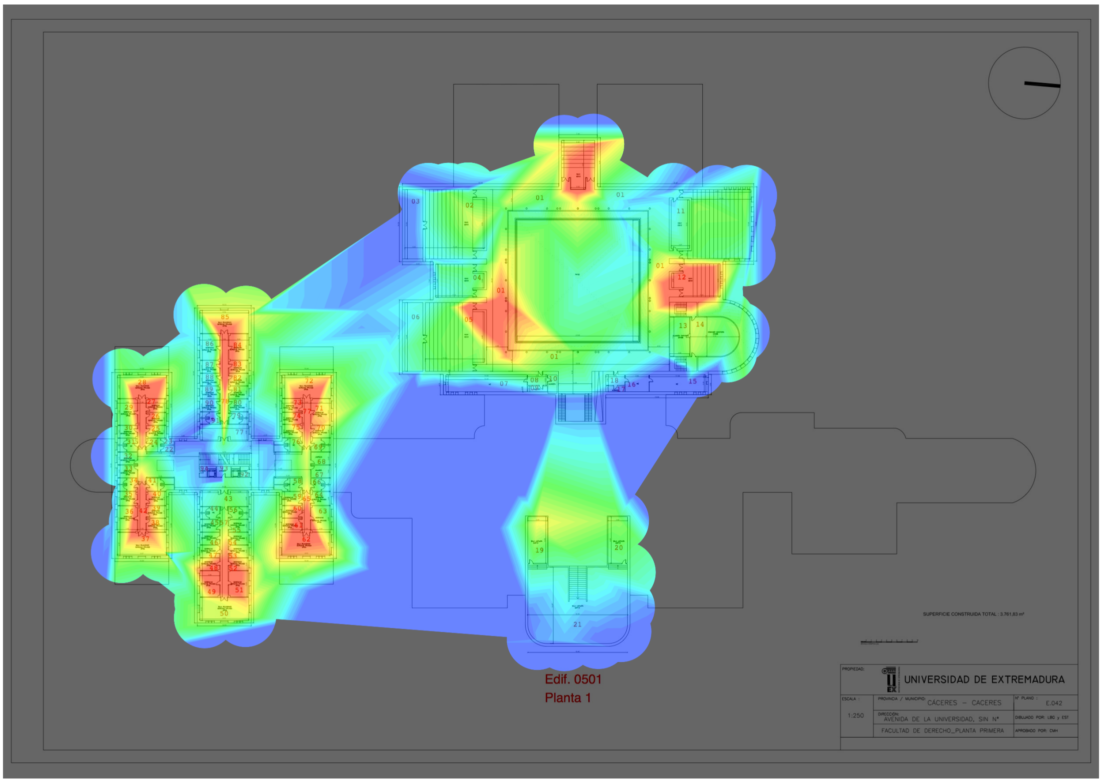
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.1.2. Building 0501 Floor 1

4.1.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

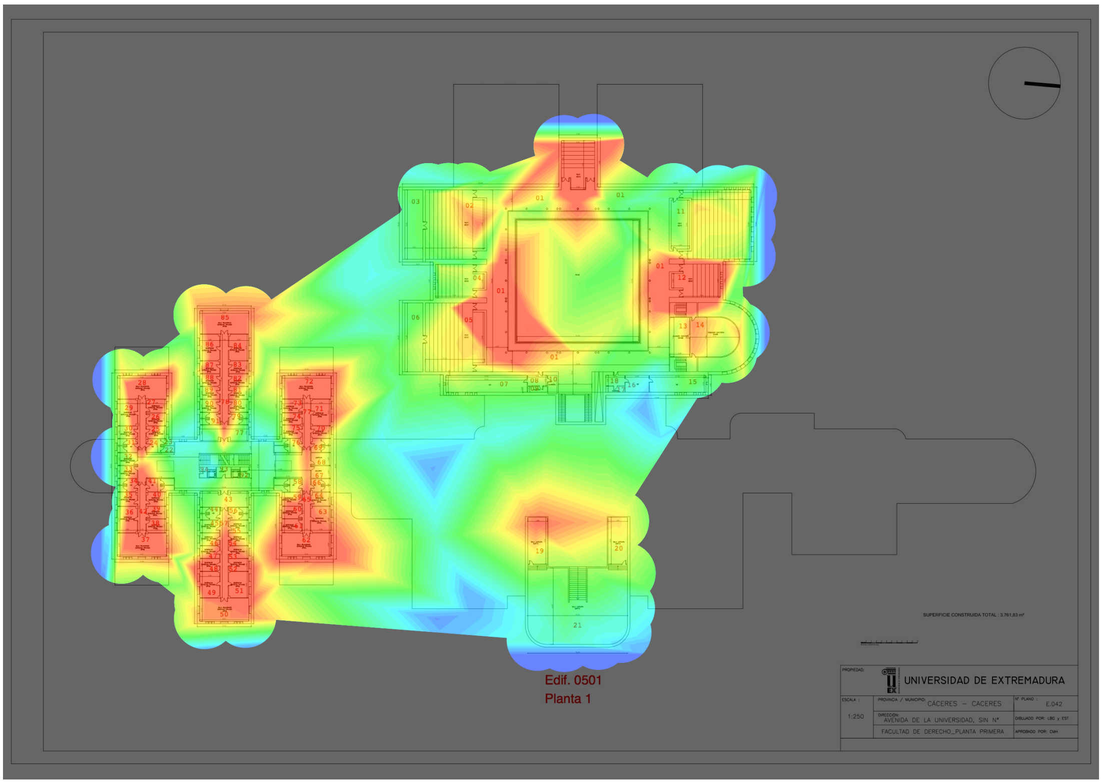


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.1.2.2. Signal Level



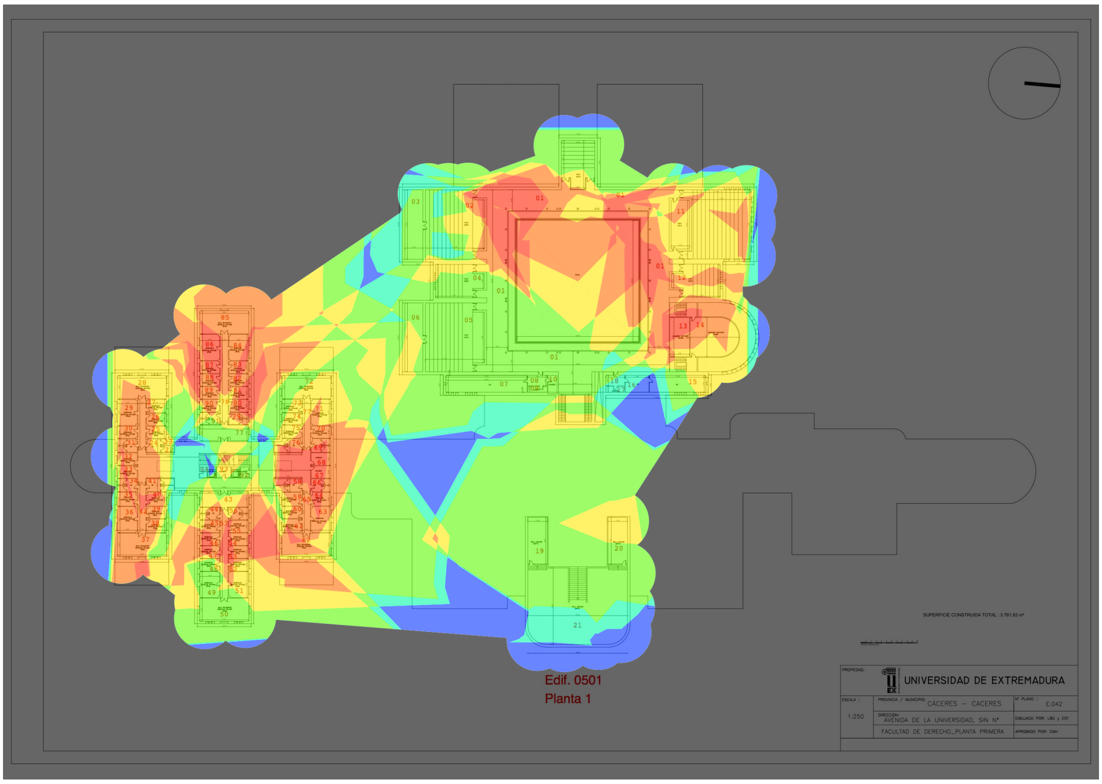
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.1.2.3. Number of Access Points

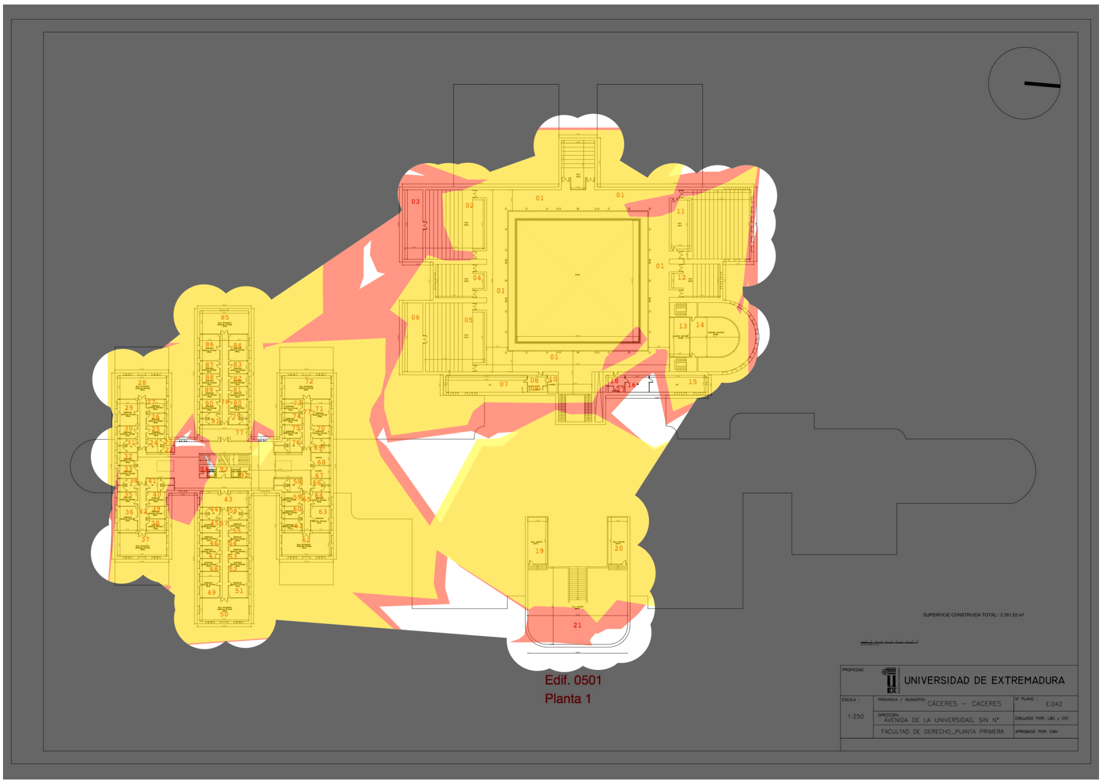


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.1.2.4. Coverage per Frequency Band



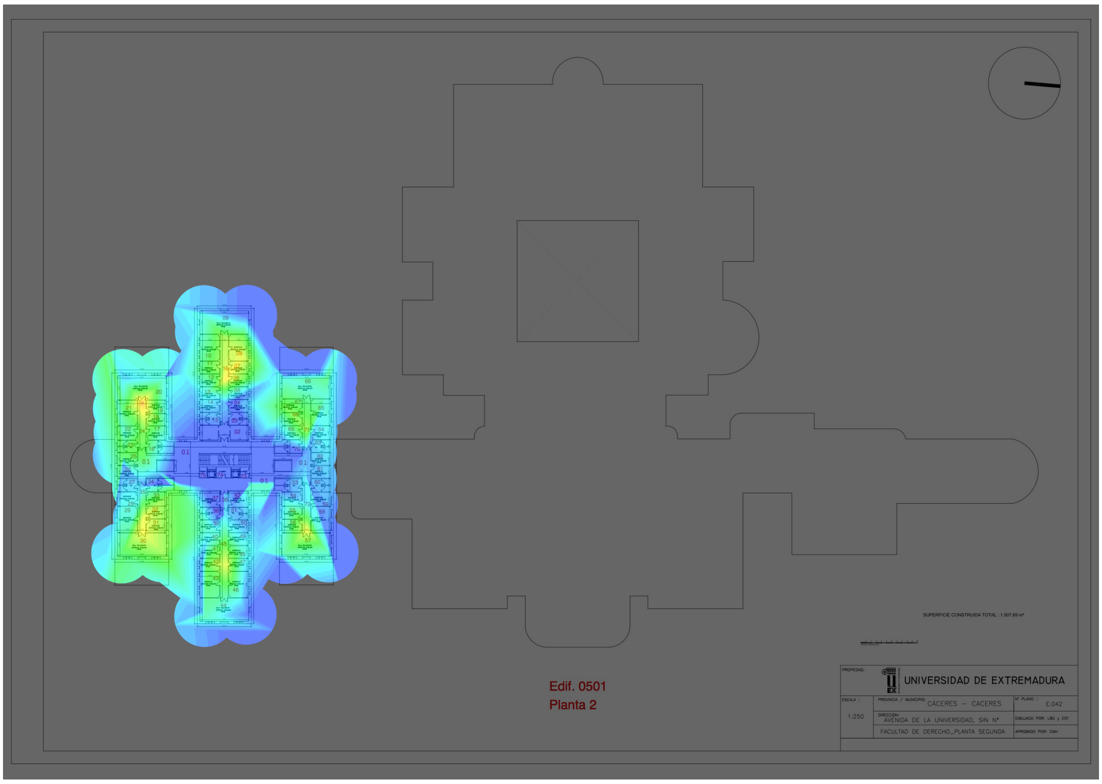
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.1.3. Building 0501 Floor 2

4.1.3.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

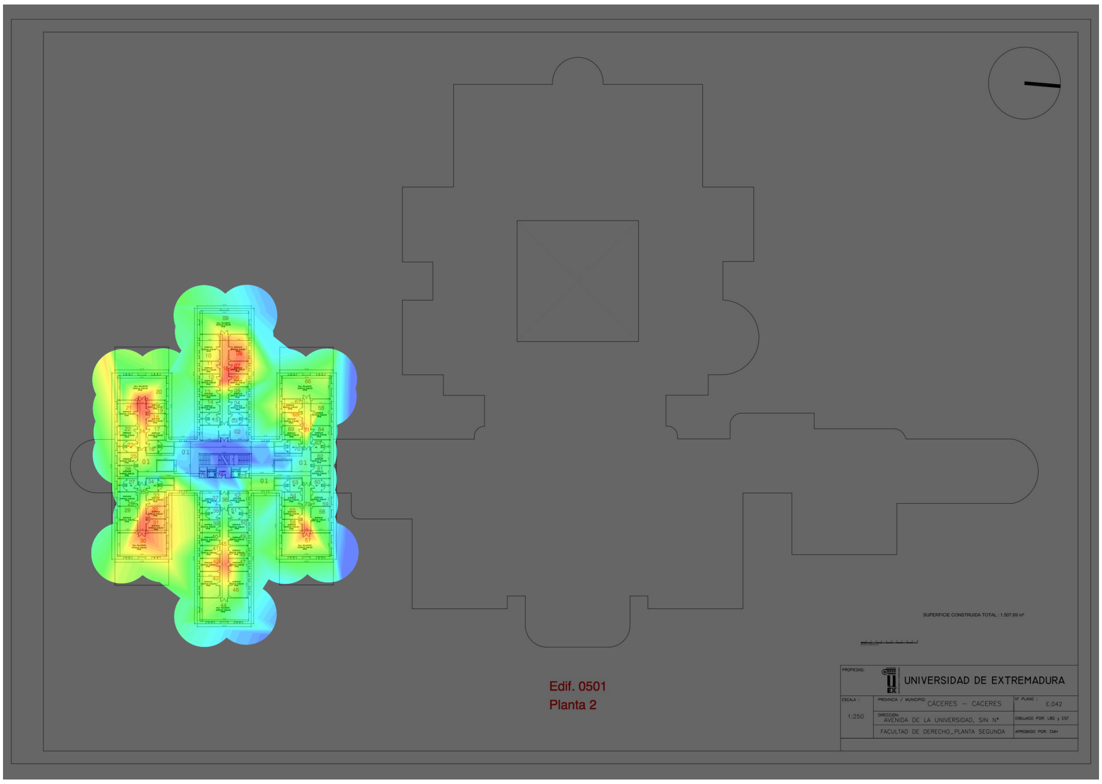


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.1.3.2. Signal Level



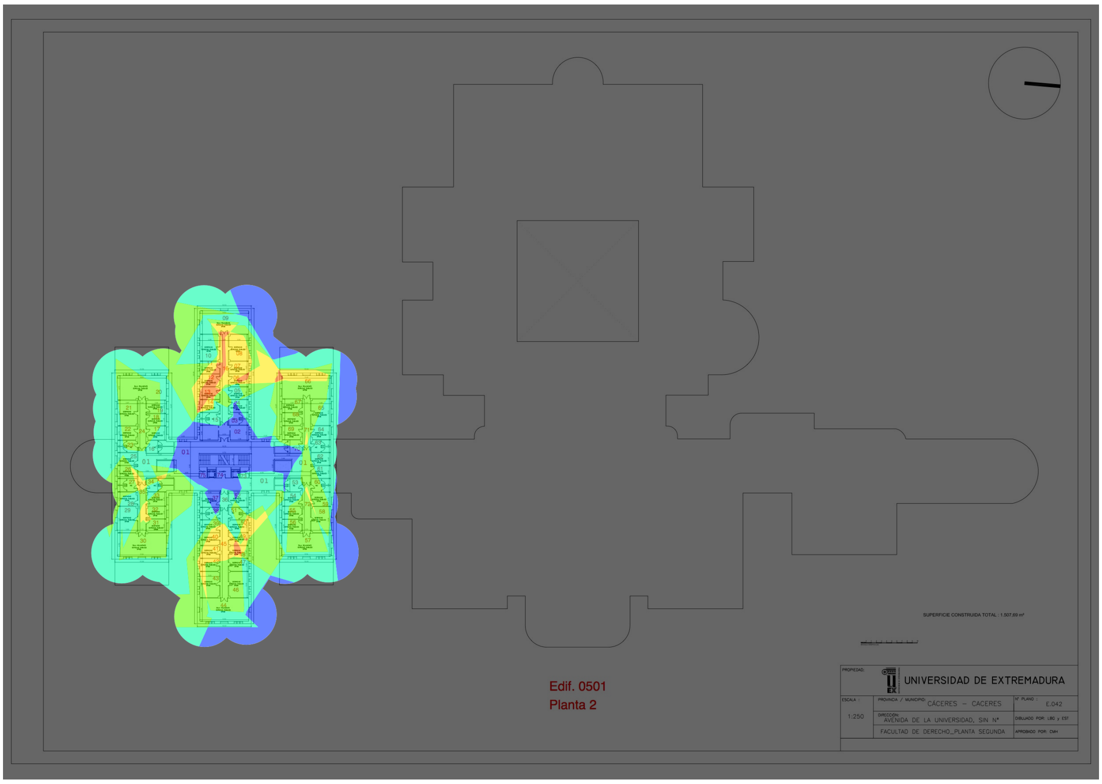
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.1.3.3. Number of Access Points

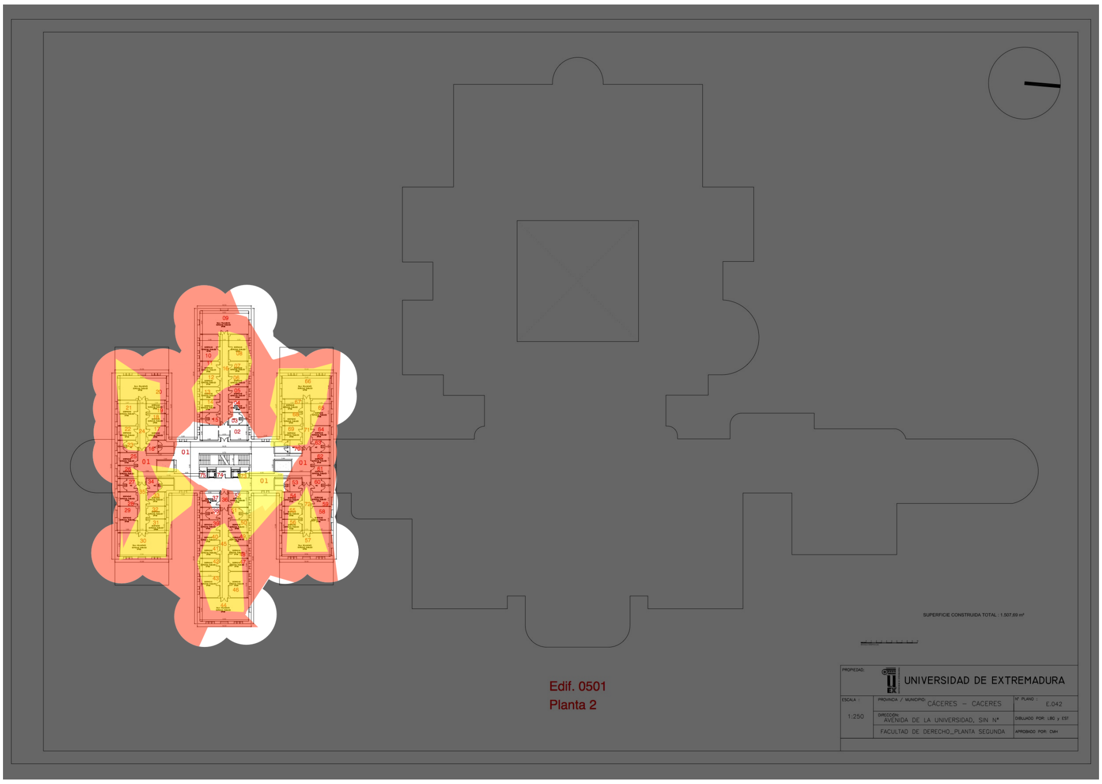


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.1.3.4. Coverage per Frequency Band



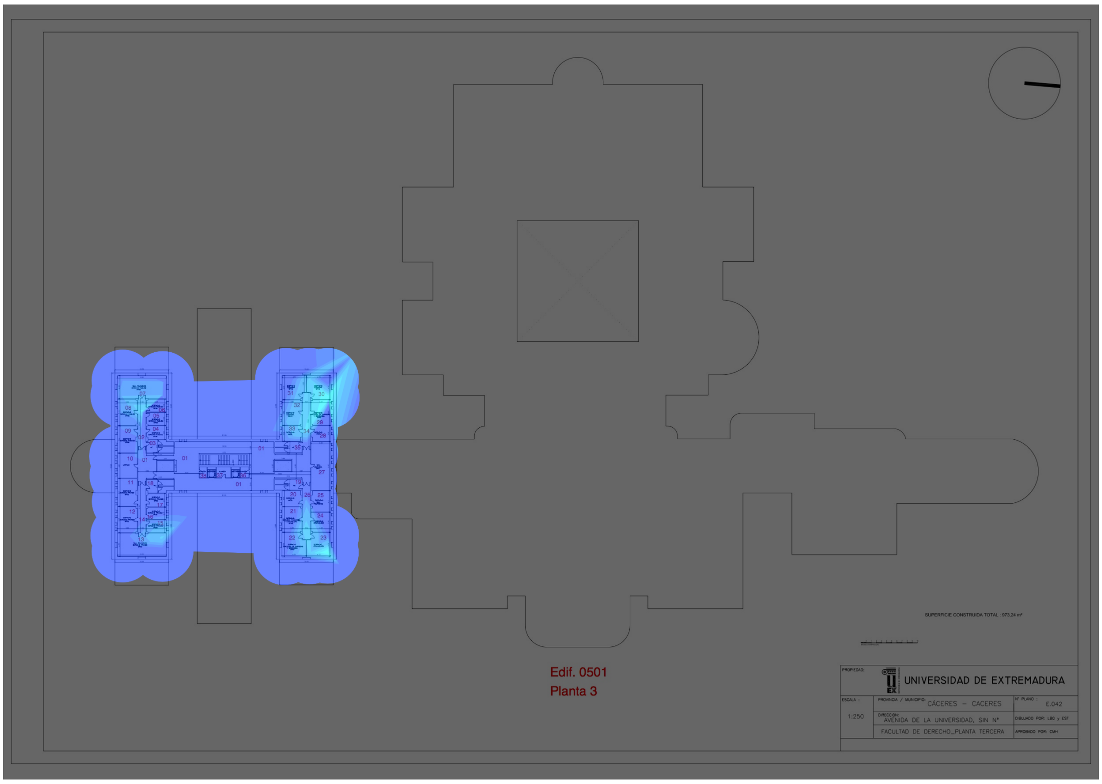
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.1.4. Building 0501 Floor 3

4.1.4.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists.



The office areas have less coverage, because teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.1.4.2. Signal Level

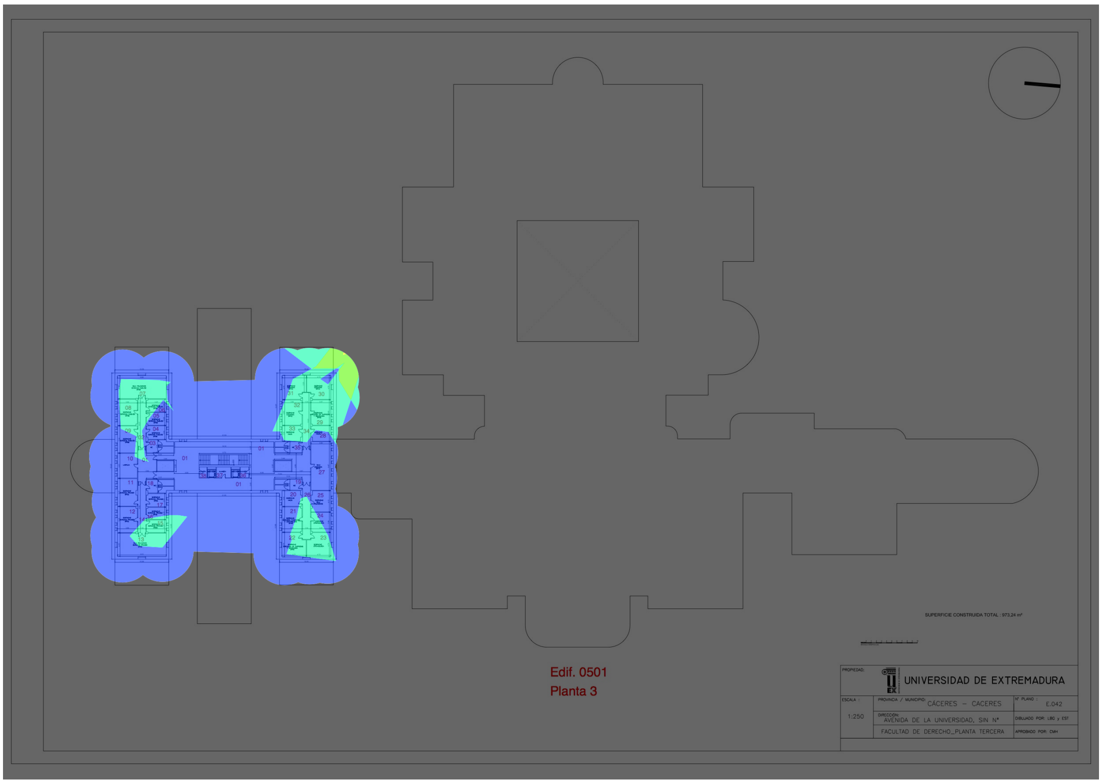
The office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.1.4.3. Number of Access Points

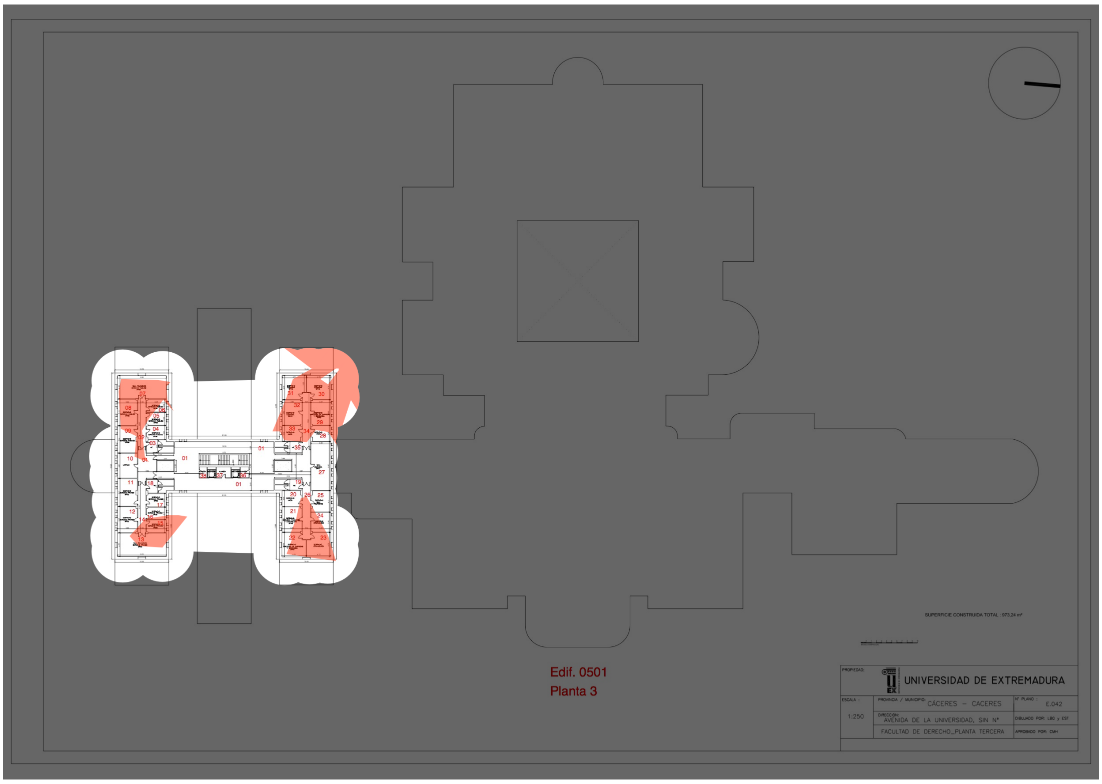


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

There is no access to them and only one or two access points available.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.1.4.4. Coverage per Frequency Band



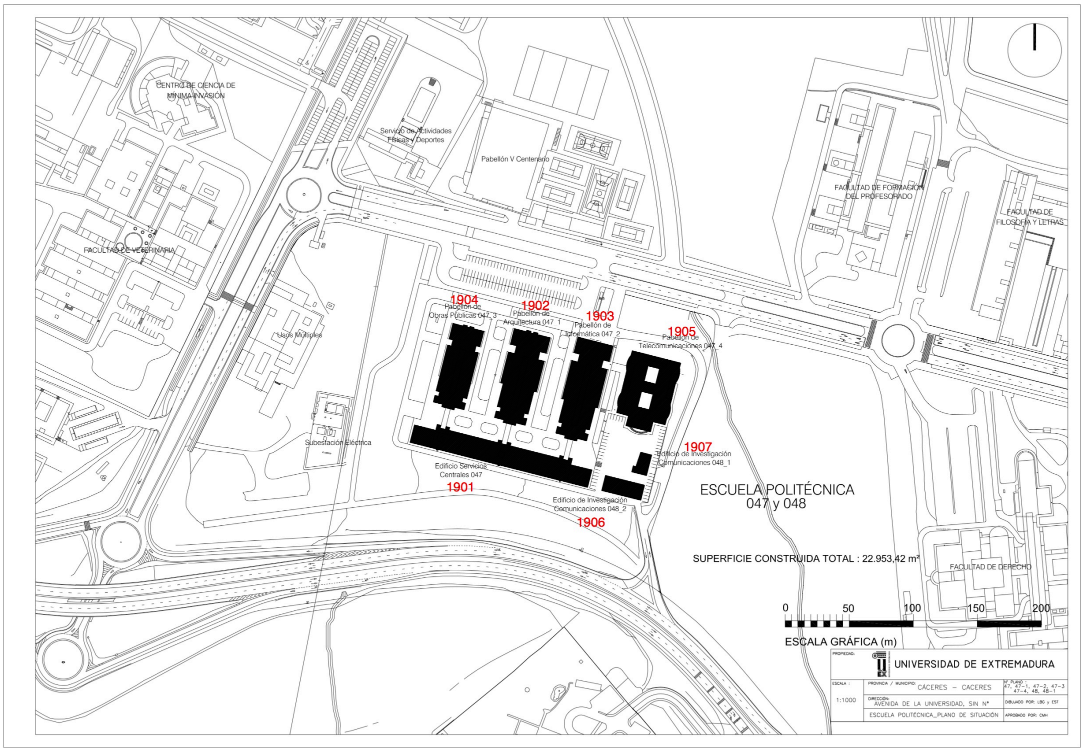
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2. Escuela Politécnica

A total of 737 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

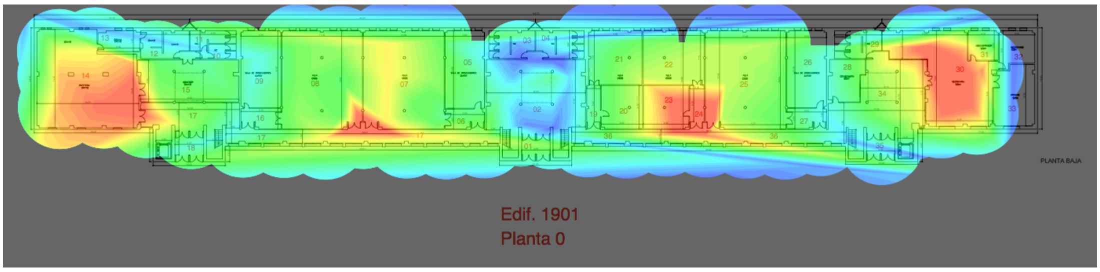
We see the location of the buildings on the following plan.



4.2.1. Building 1901 Floor 0

4.2.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

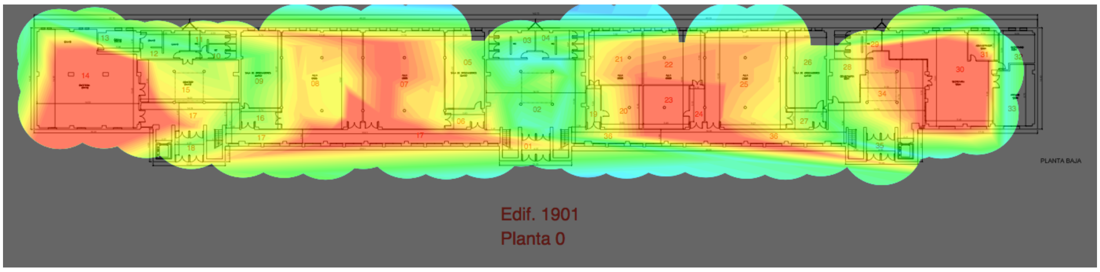


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.1.2. Signal Level



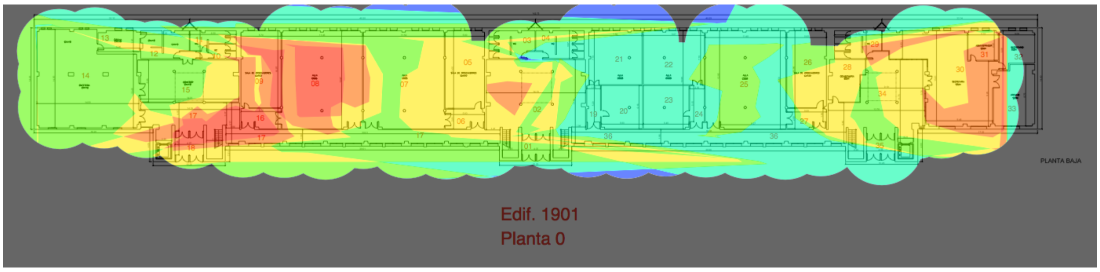
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.1.3. Number of Access Points

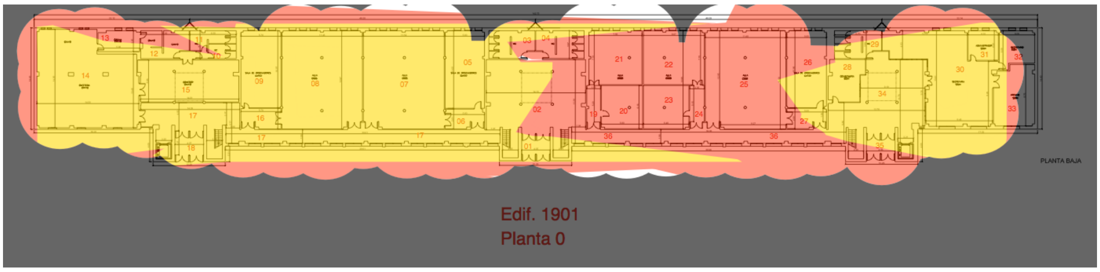


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.1.4. Coverage per Frequency Band



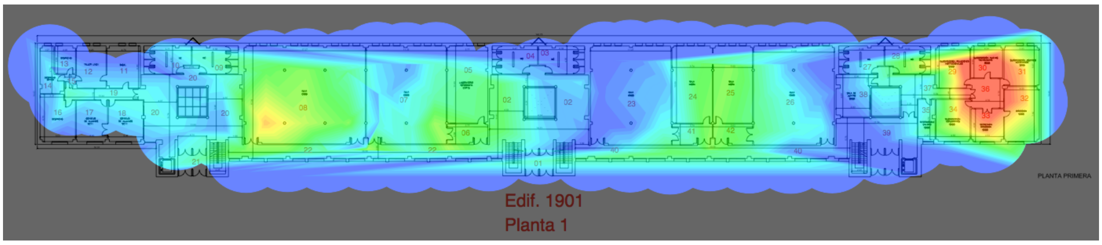
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.2. Building 1901 Floor 1

4.2.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

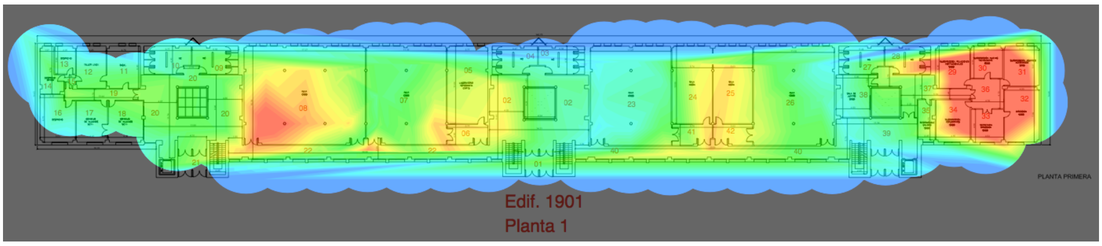


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.2.2. Signal Level



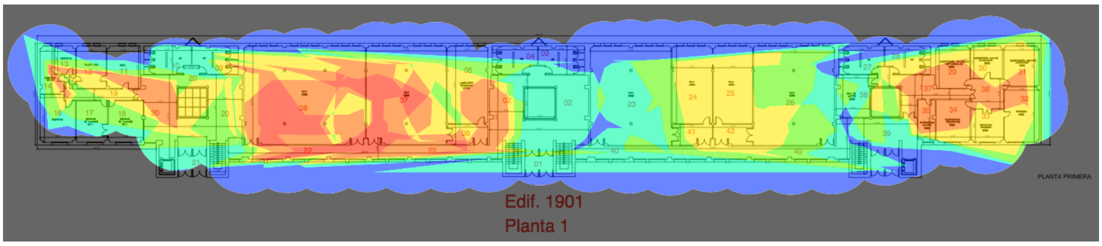
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.2.3. Number of Access Points

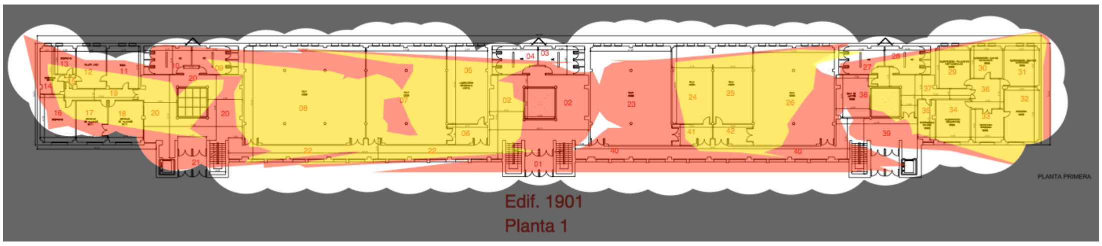


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.2.4. Coverage per Frequency Band



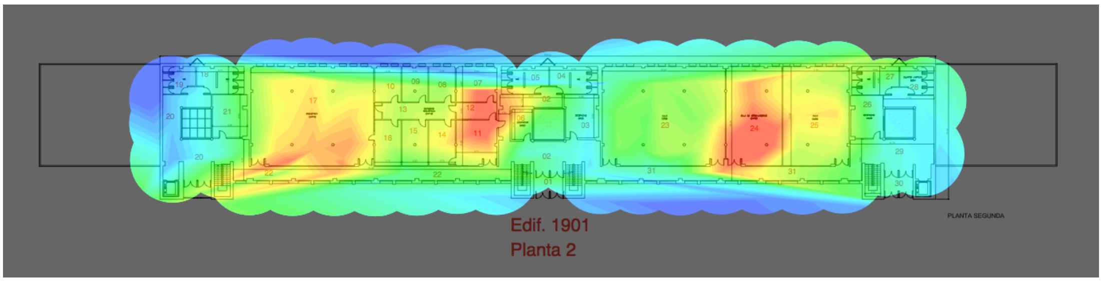
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.3. Building 1901 Floor 2

4.2.3.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

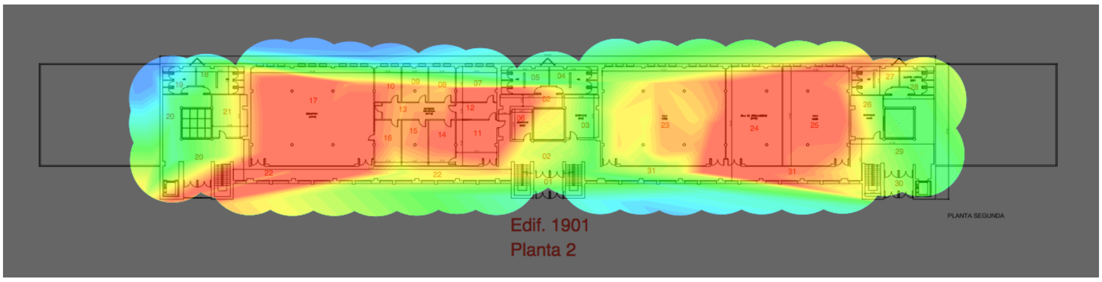


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.3.2. Signal Level



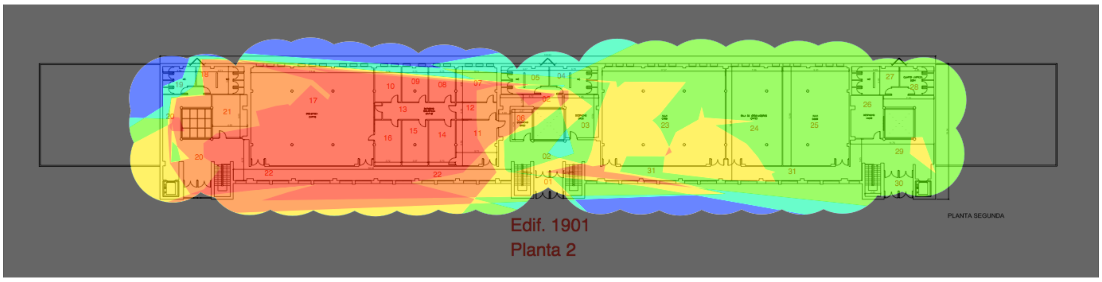
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.3.3. Number of Access Points

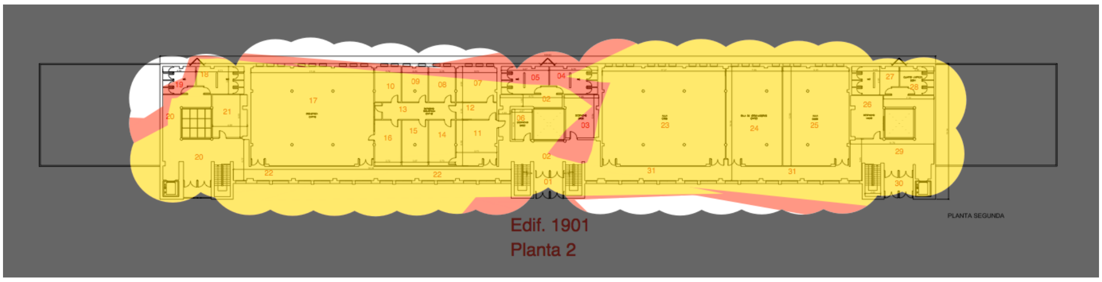


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.3.4. Coverage per Frequency Band



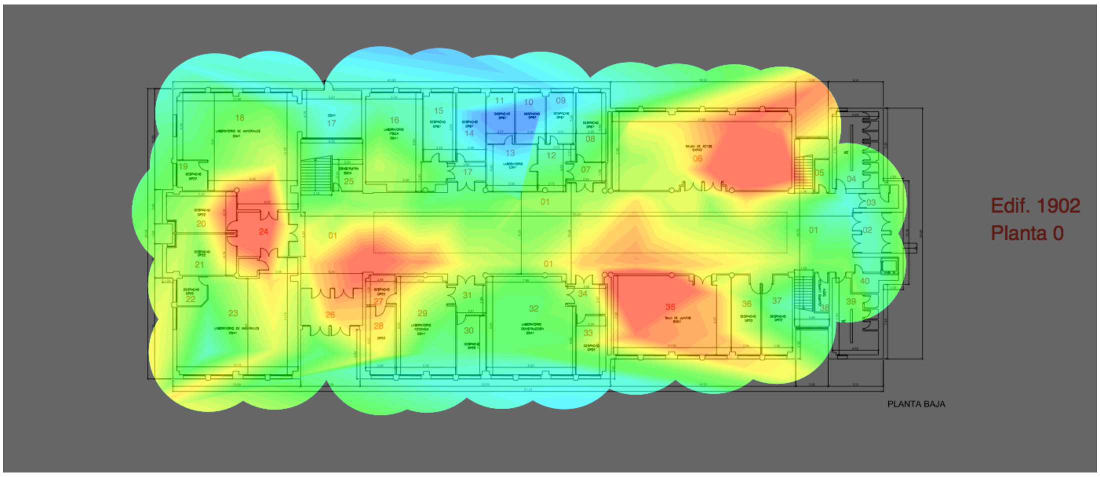
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.11. Building 1902 Floor 0

4.2.11.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

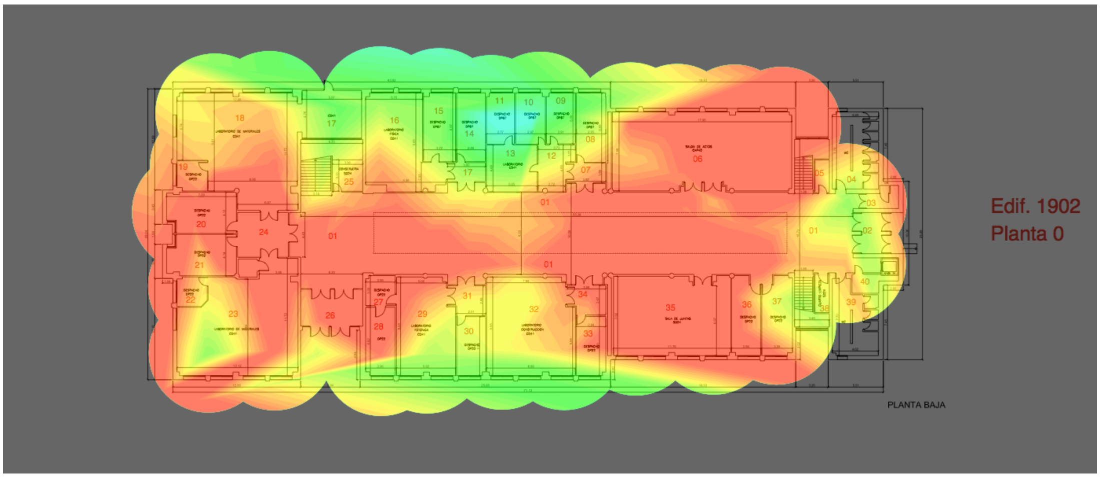


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.11.2. Signal Level



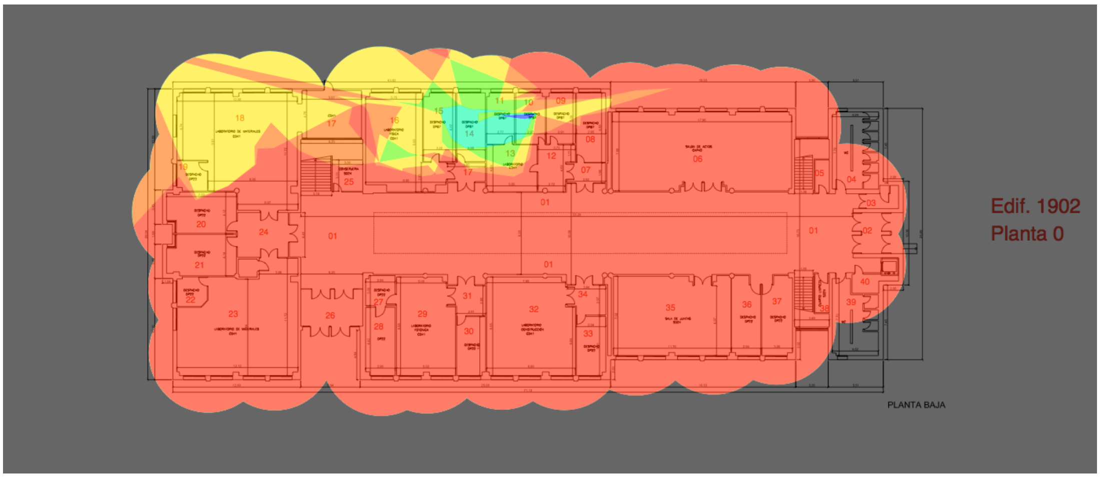
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.11.3. Number of Access Points

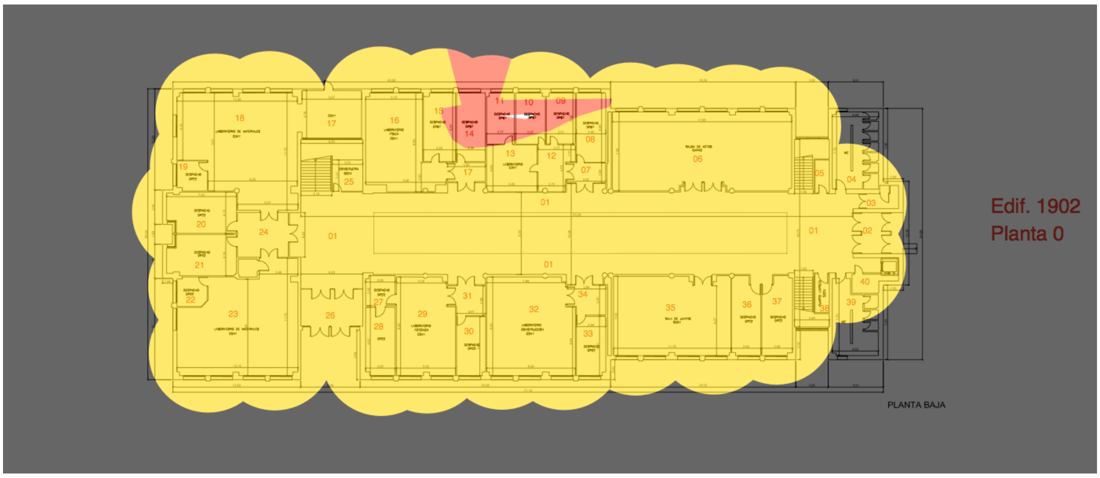


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.11.4. Coverage per Frequency Band



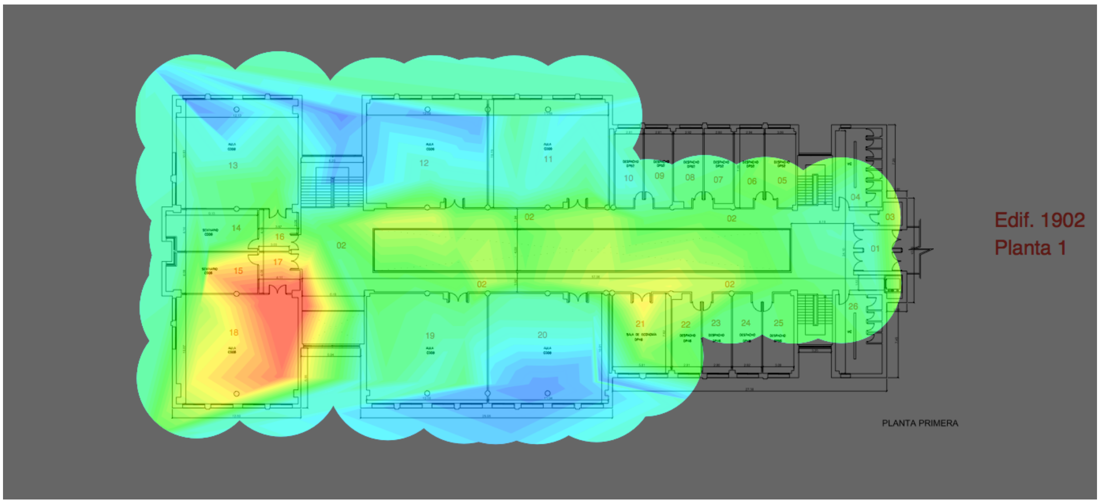
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.12. Building 1902 Floor 1

4.2.12.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

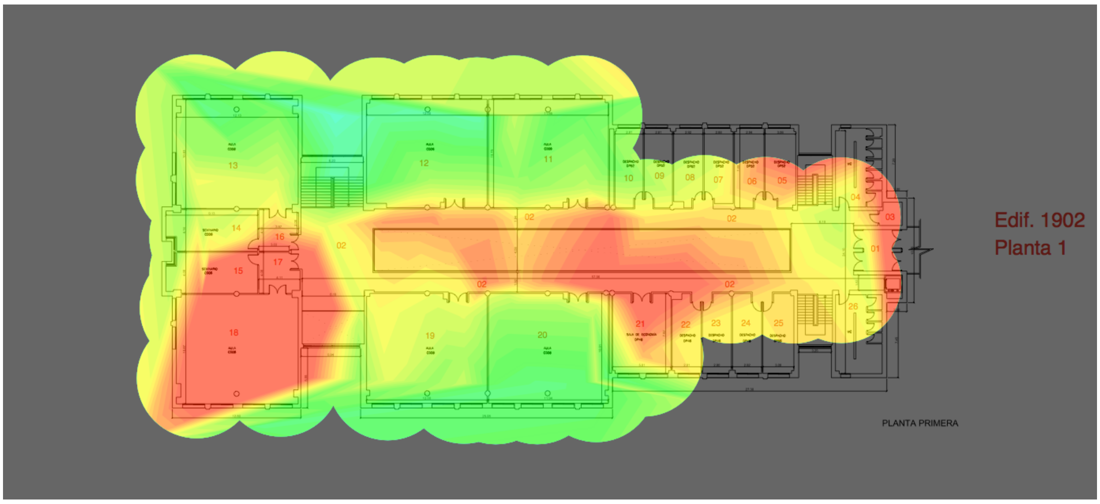


It can be seen that the areas where the classrooms are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.12.2. Signal Level



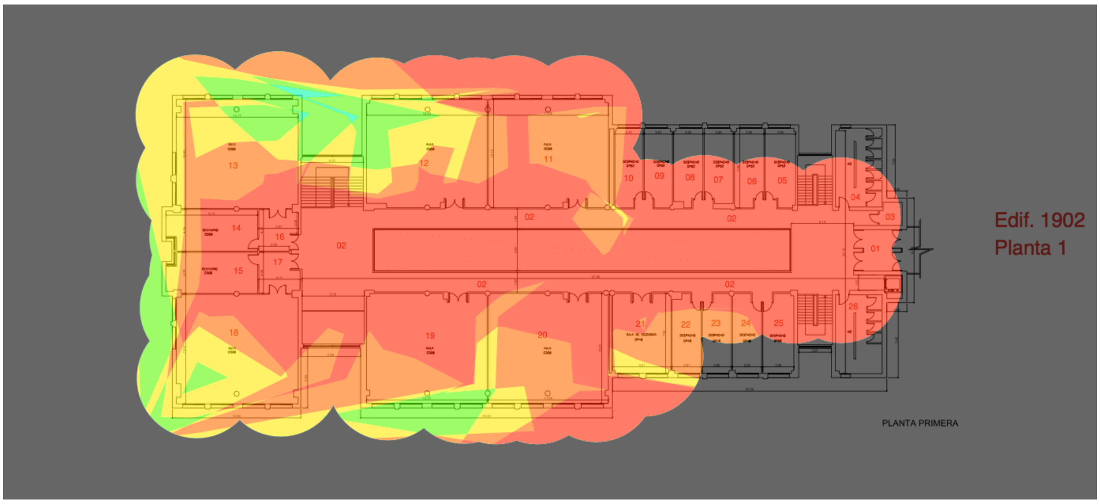
In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.12.3. Number of Access Points

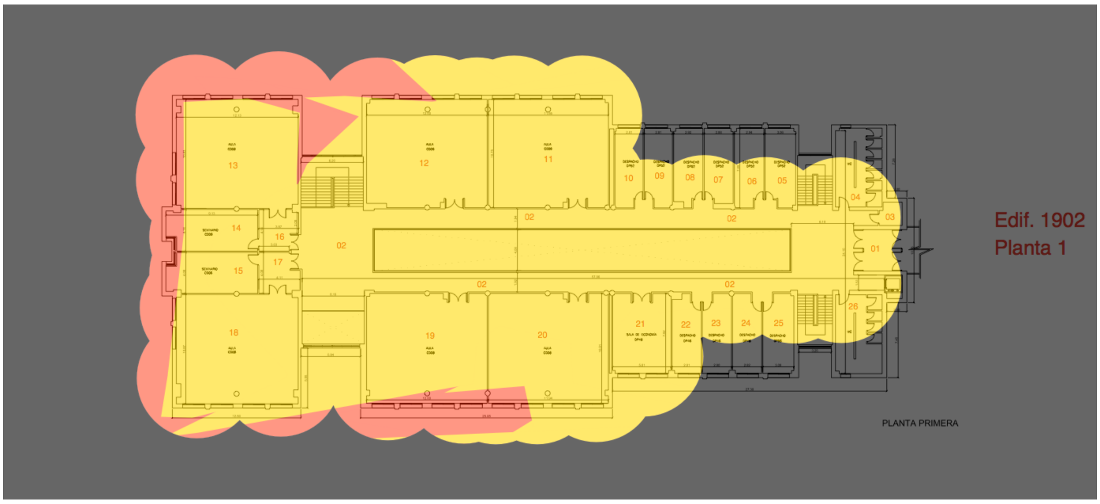


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.12.4. Coverage per Frequency Band



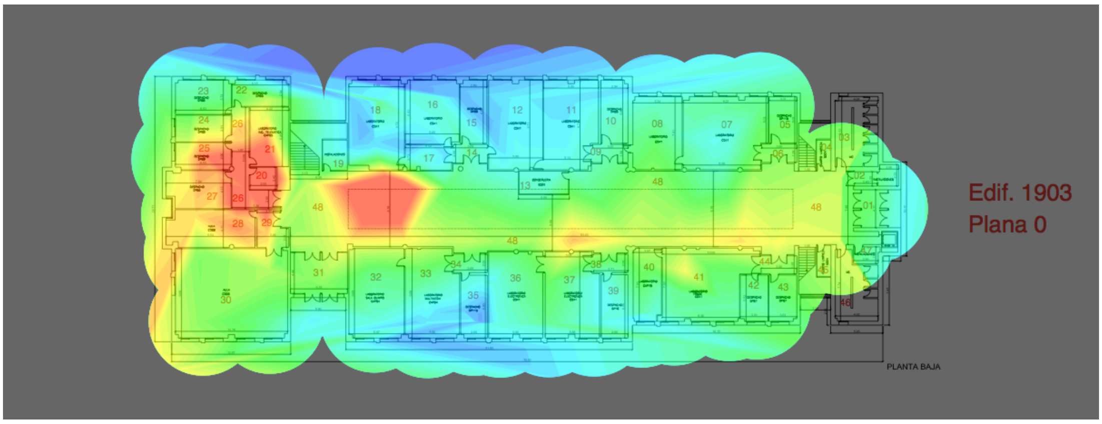
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.21. Building 1903 Floor 0

4.2.21.1. Relación Señal-Ruido

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

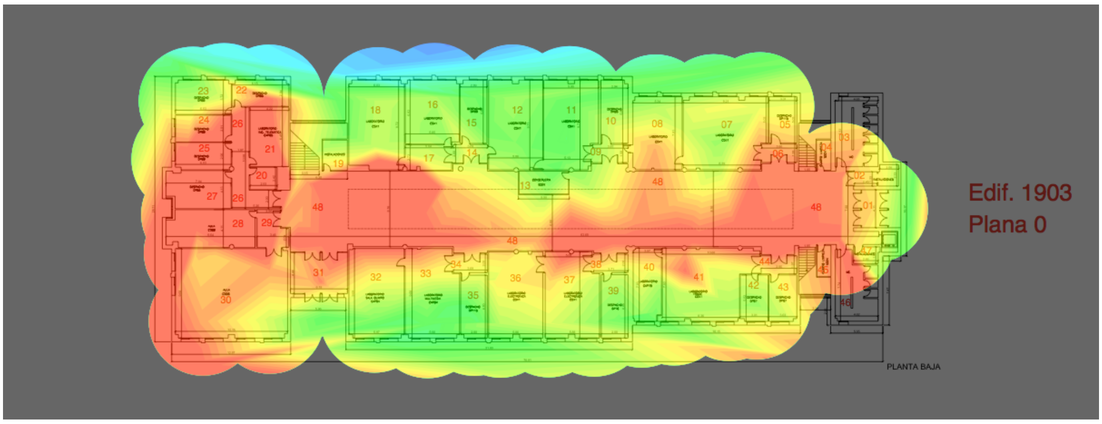


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.21.2. Signal Level



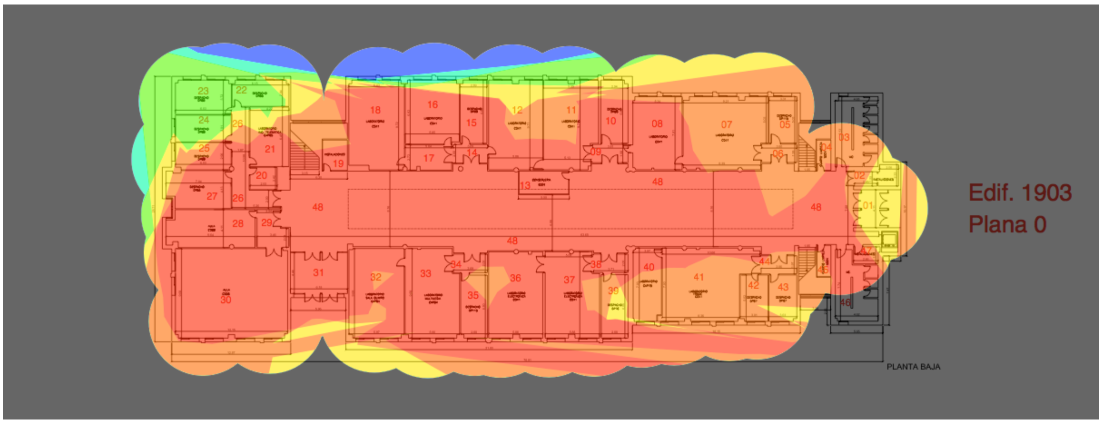
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.21.3. Number of Access Points

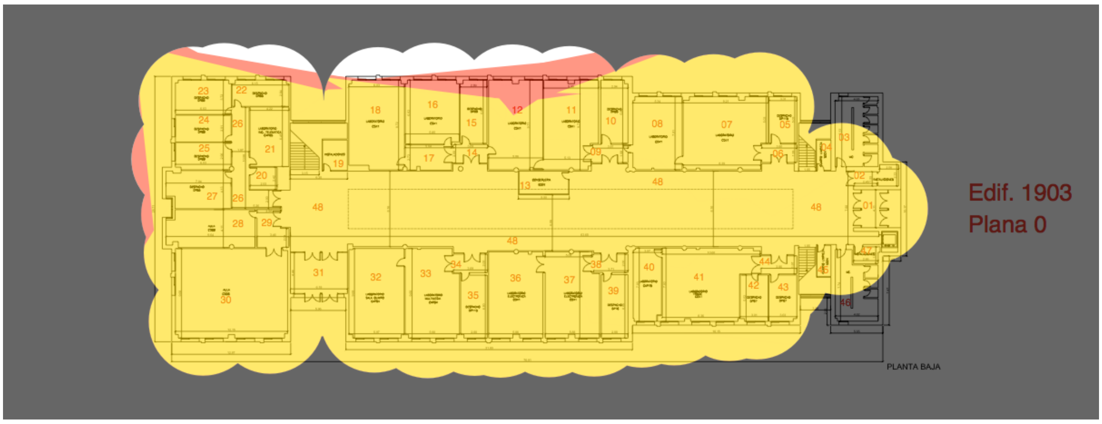


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.21.4. Coverage per Frequency Band



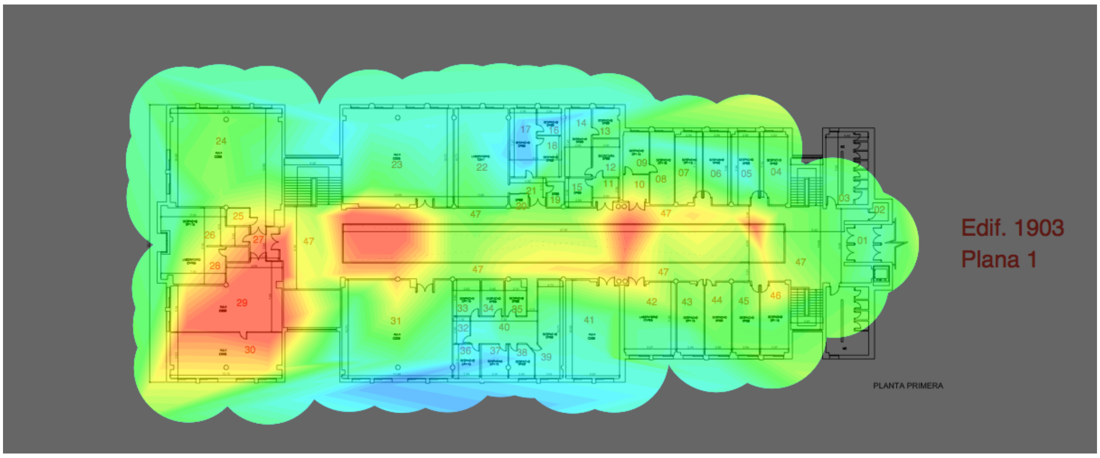
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.22. Building 1902 Floor 1

4.2.22.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

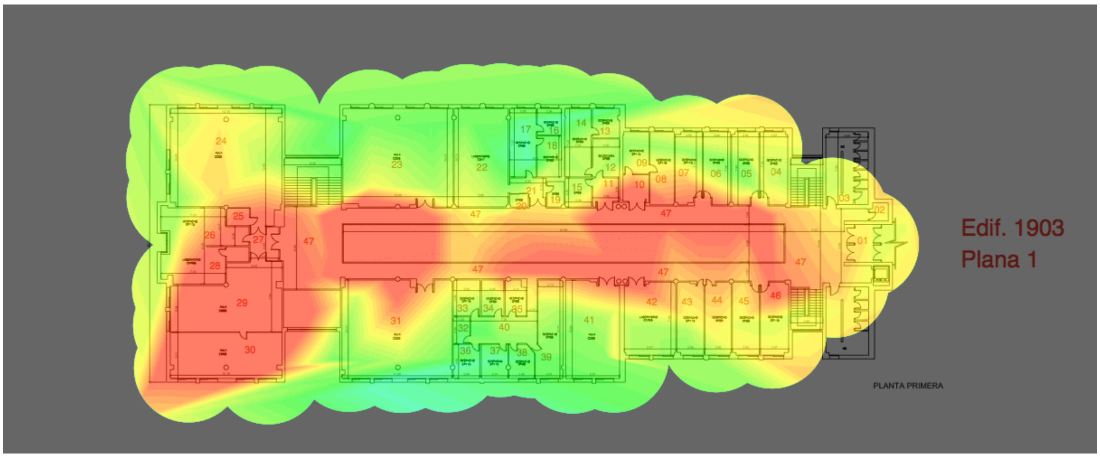


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.22.2. Signal Level



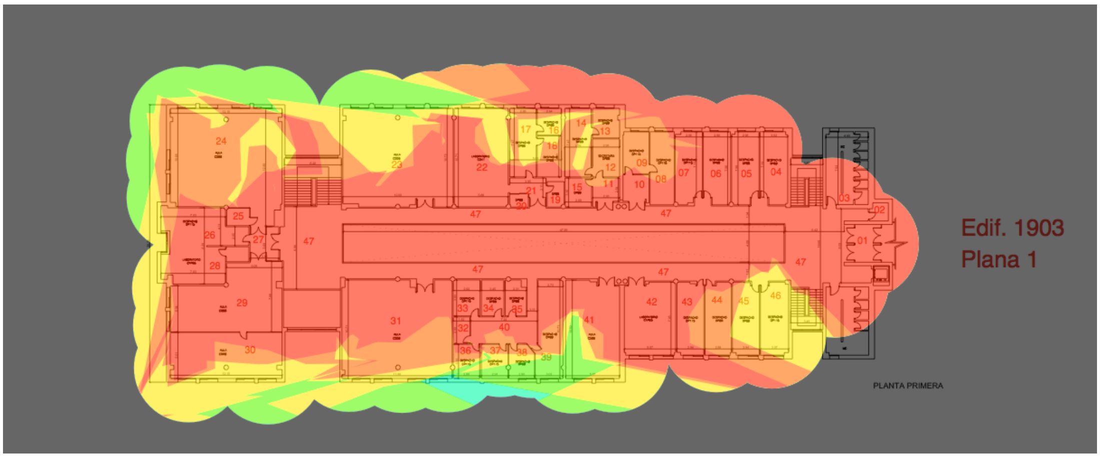
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.22.3. Number of Access Points

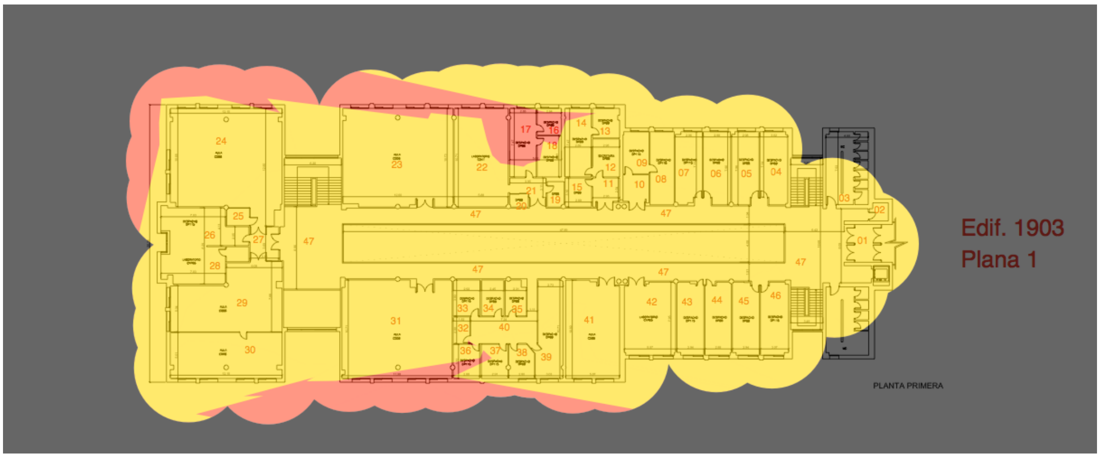


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.22.4. Coverage per Frequency Band



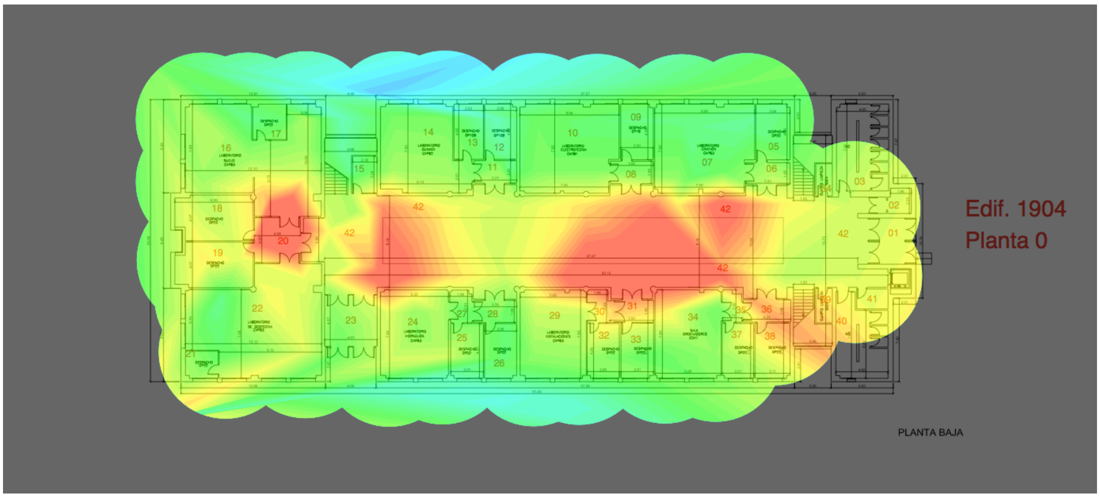
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.31. Building 1904 Floor 0

4.2.31.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

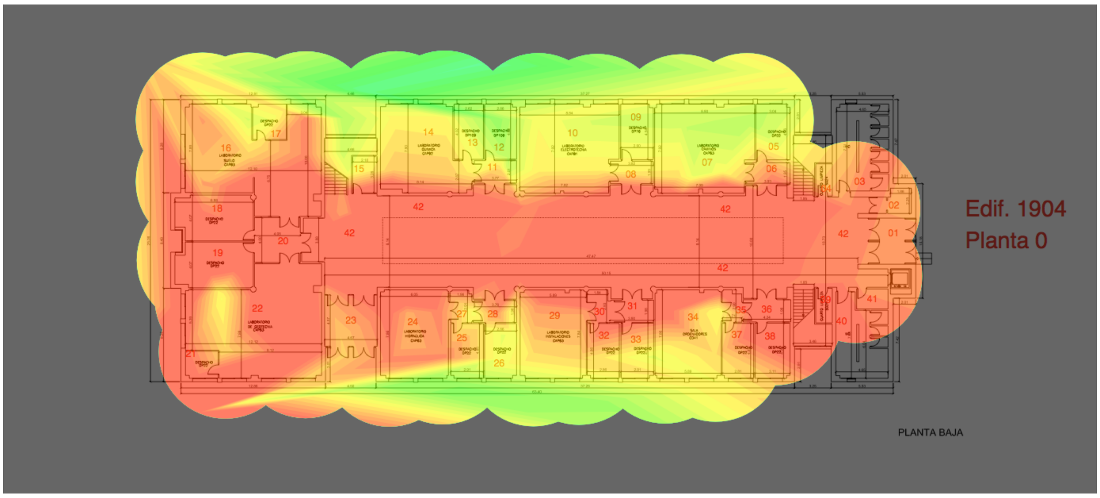


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.31.2. Signal Level



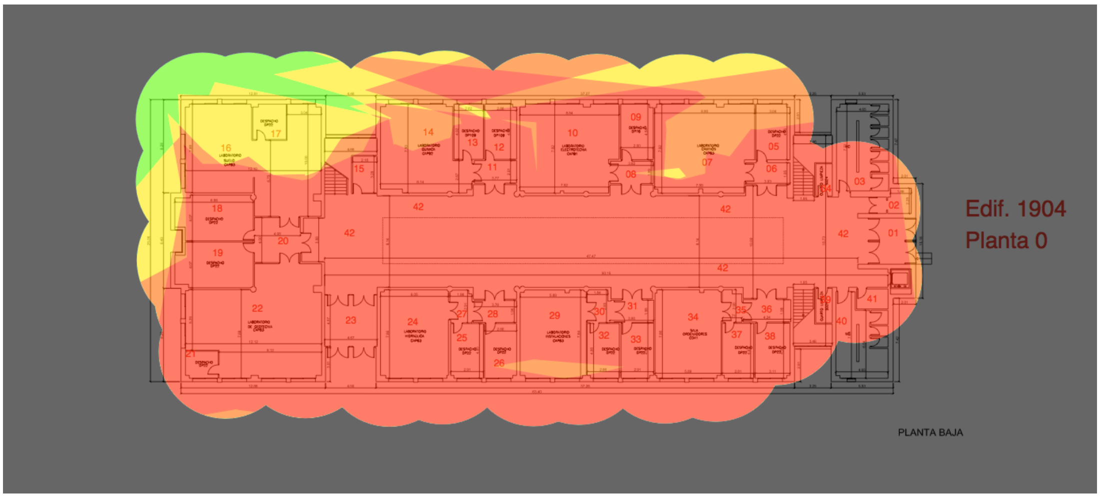
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.31.3. Number of Access Points

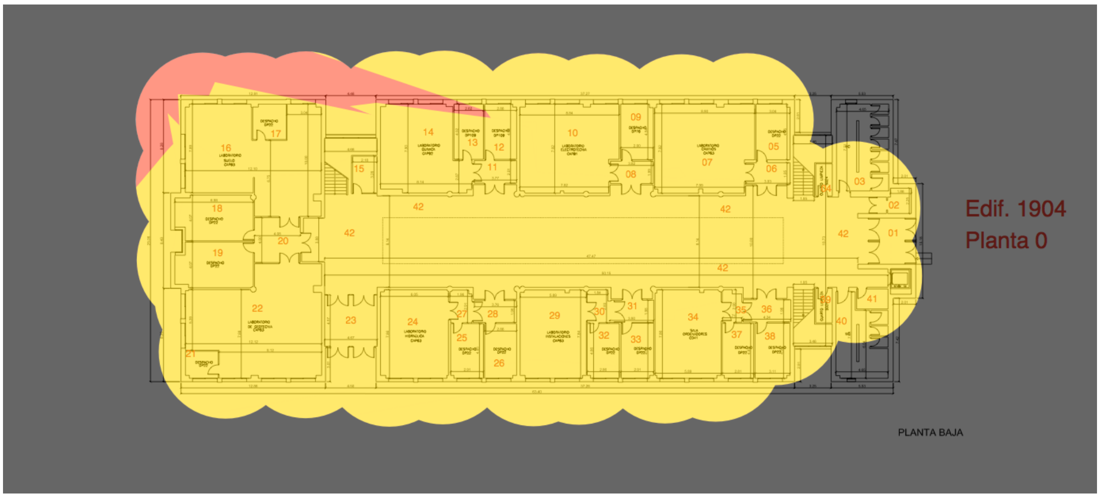


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.31.4. Coverage per Frequency Band



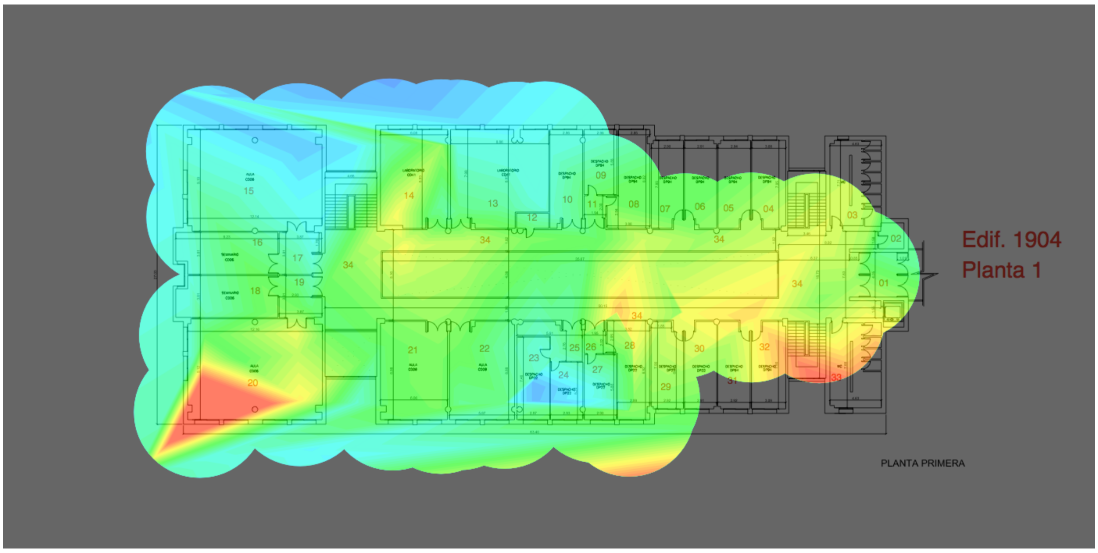
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.32. Building 1904 Floor 1

4.2.32.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

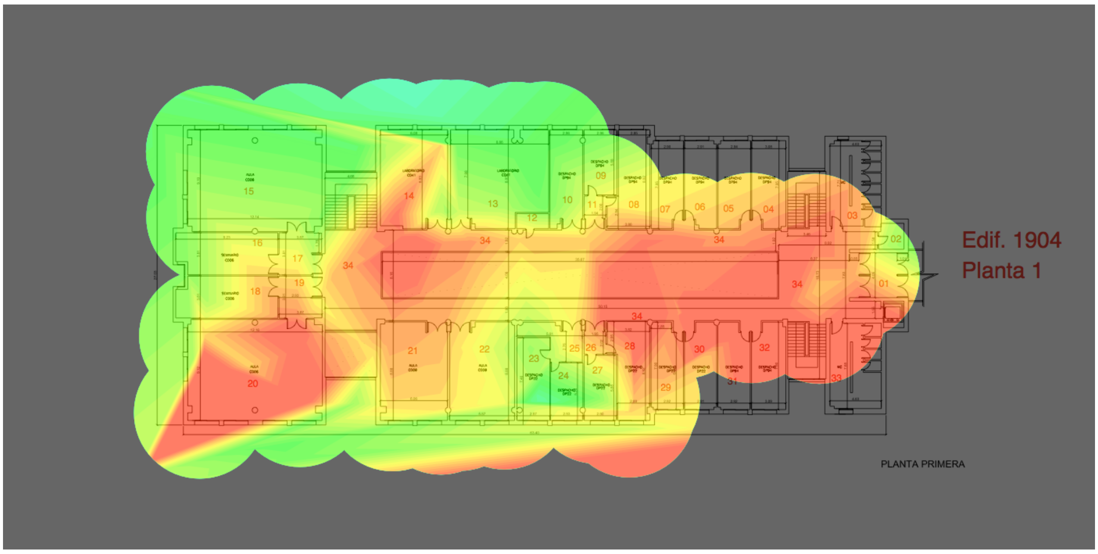


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.32.2. Signal Level



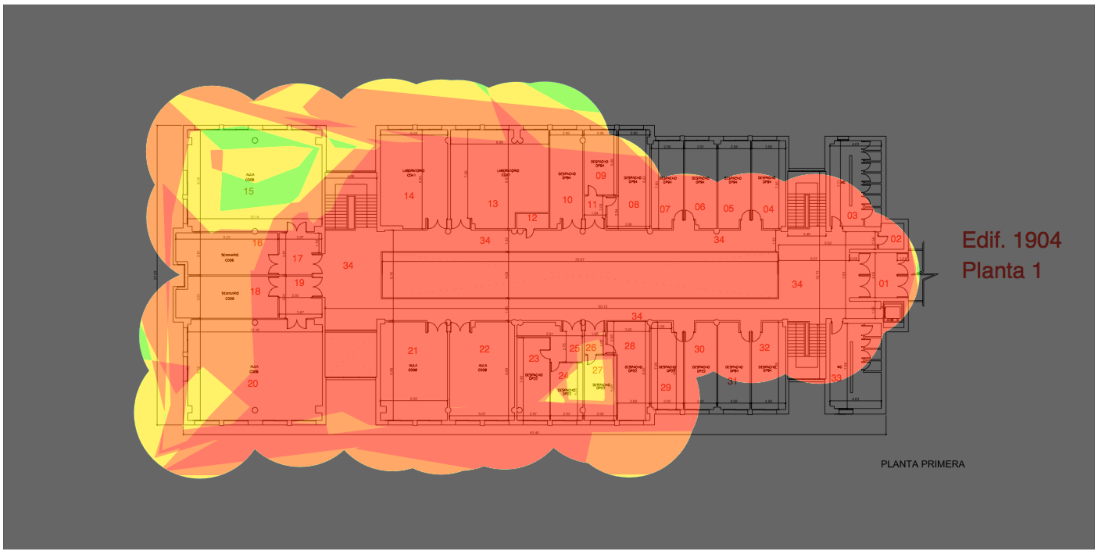
In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.32.3. Number of Access Points

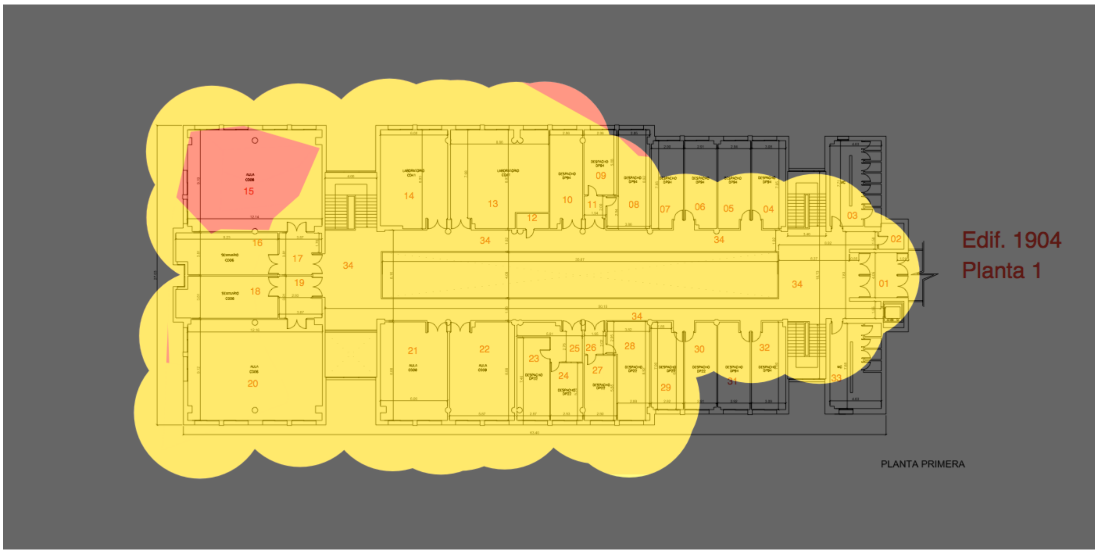


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.32.4. Coverage per Frequency Band



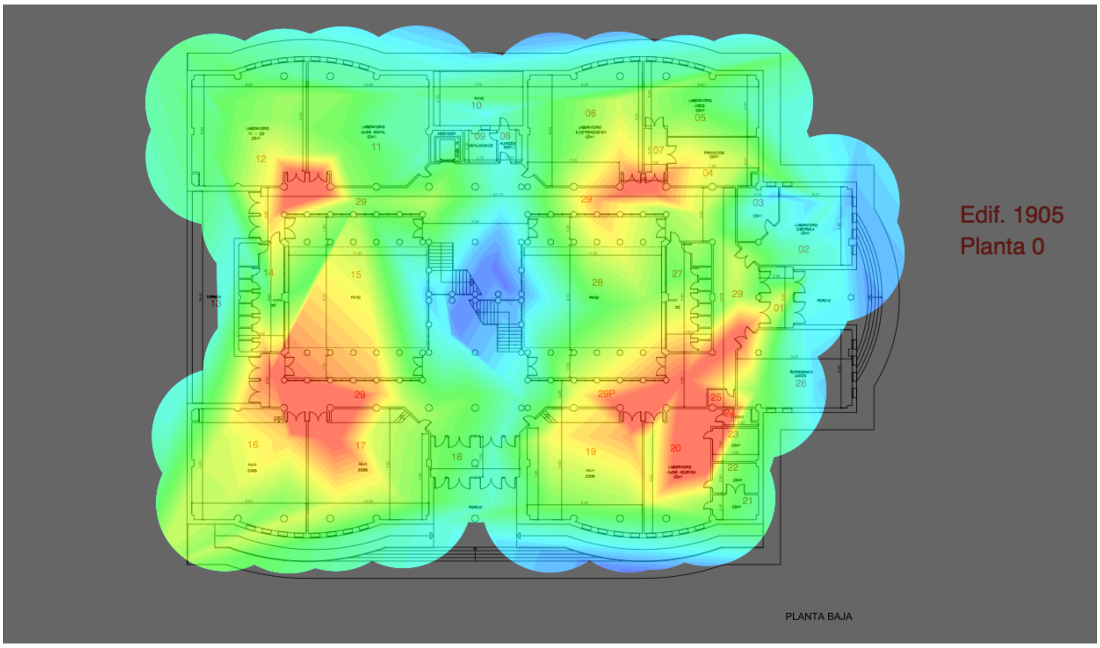
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.41. Building 1905 Floor 0

4.2.41.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

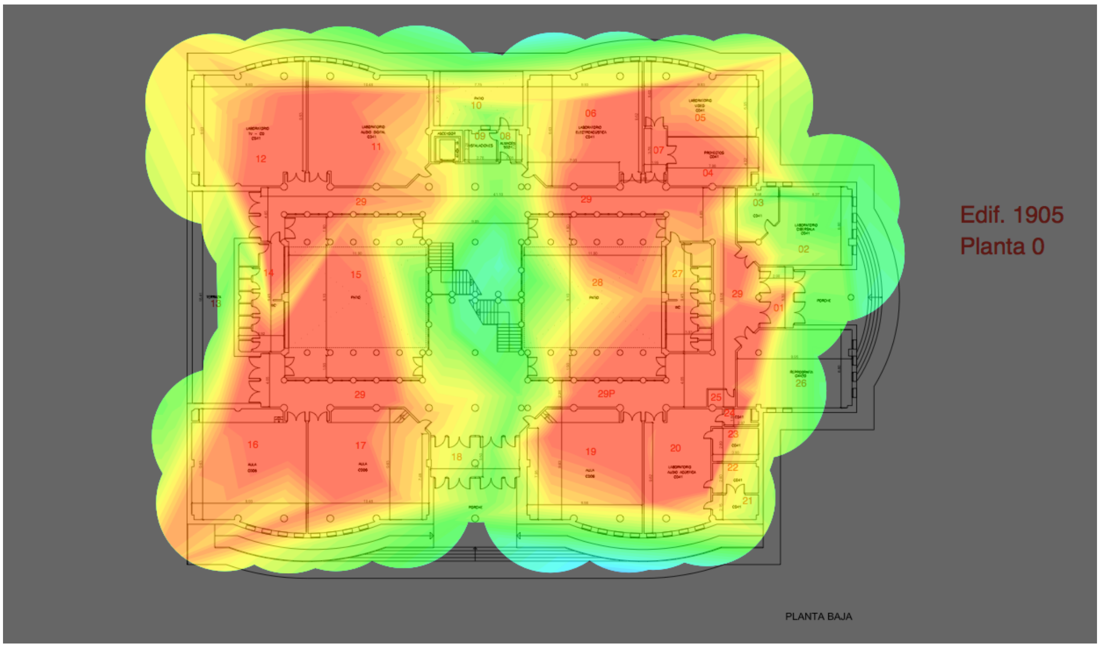


It can be seen that the areas where the classrooms are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.41.2. Signal Level



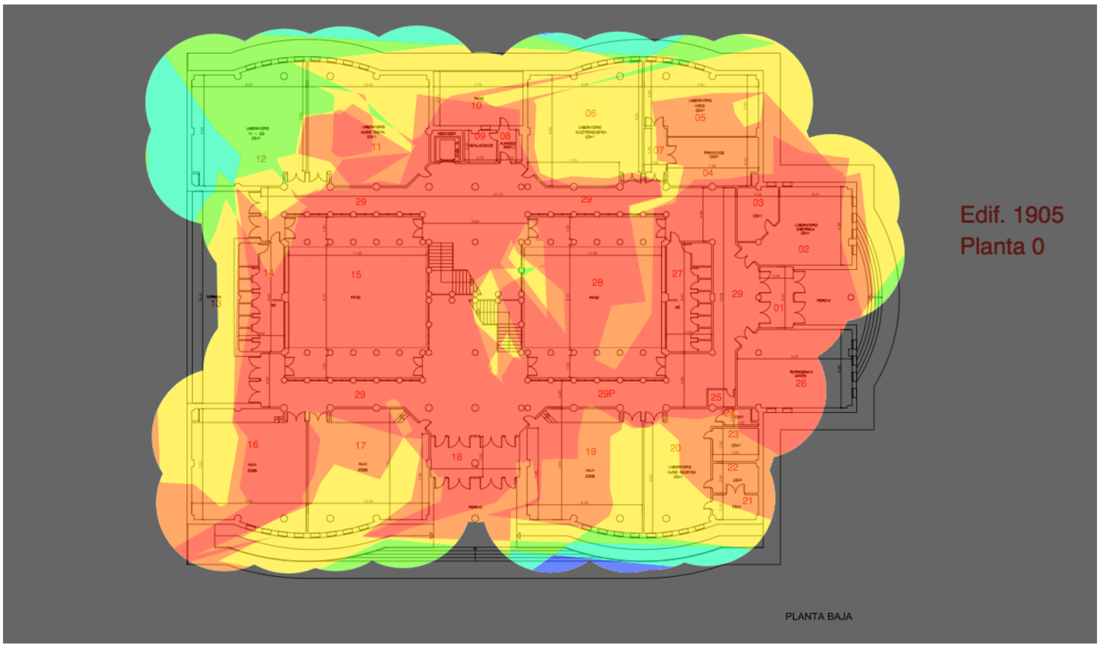
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.41.3. Number of Access Points

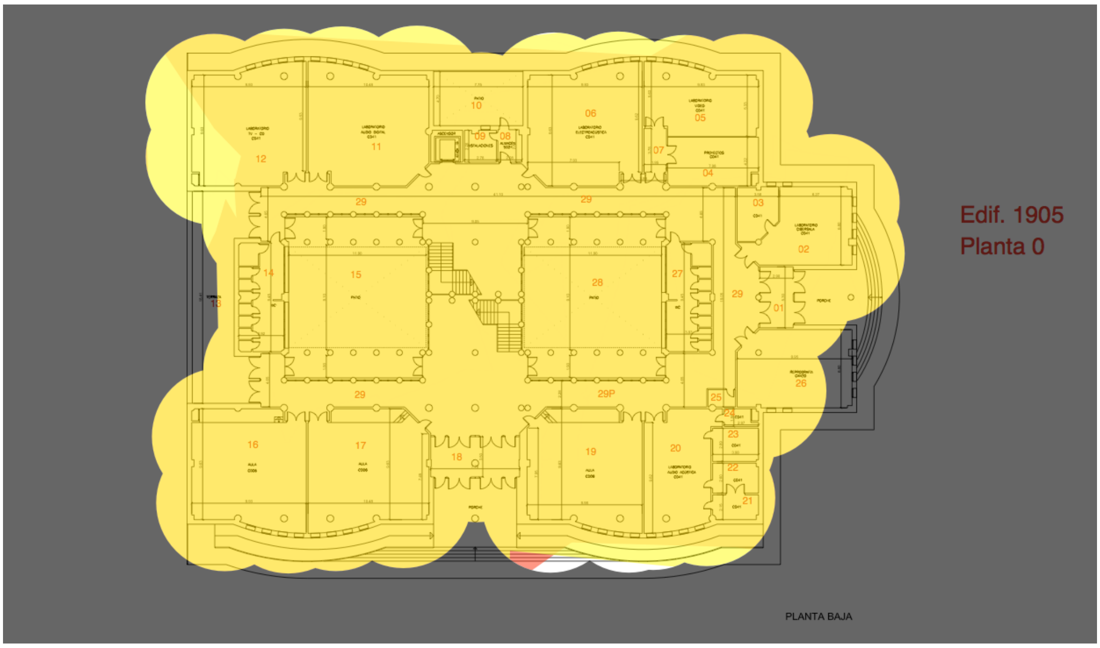


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.41.4. Coverage per Frequency Band



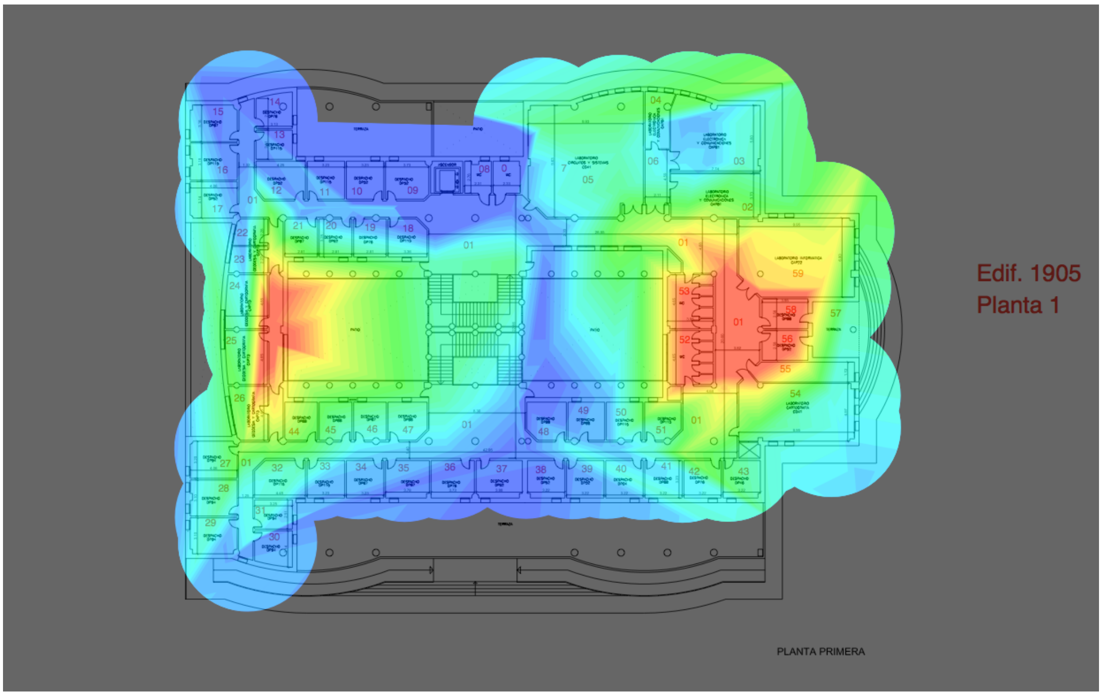
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.42. Building 1905 Floor 1

4.2.42.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

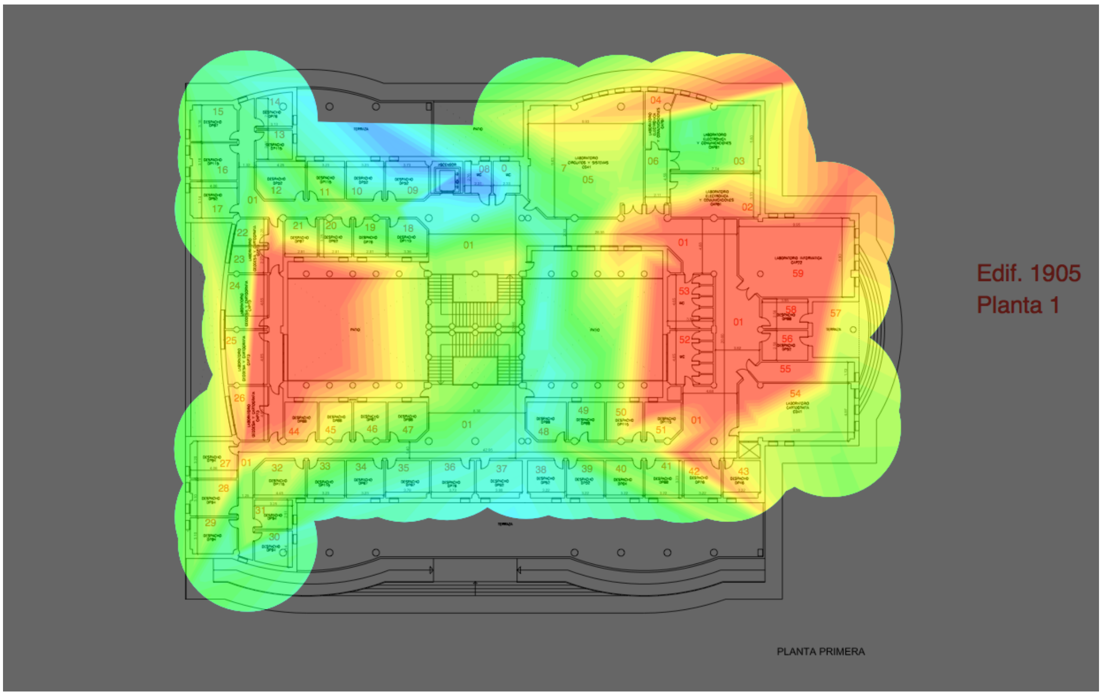


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.42.2. Signal Level



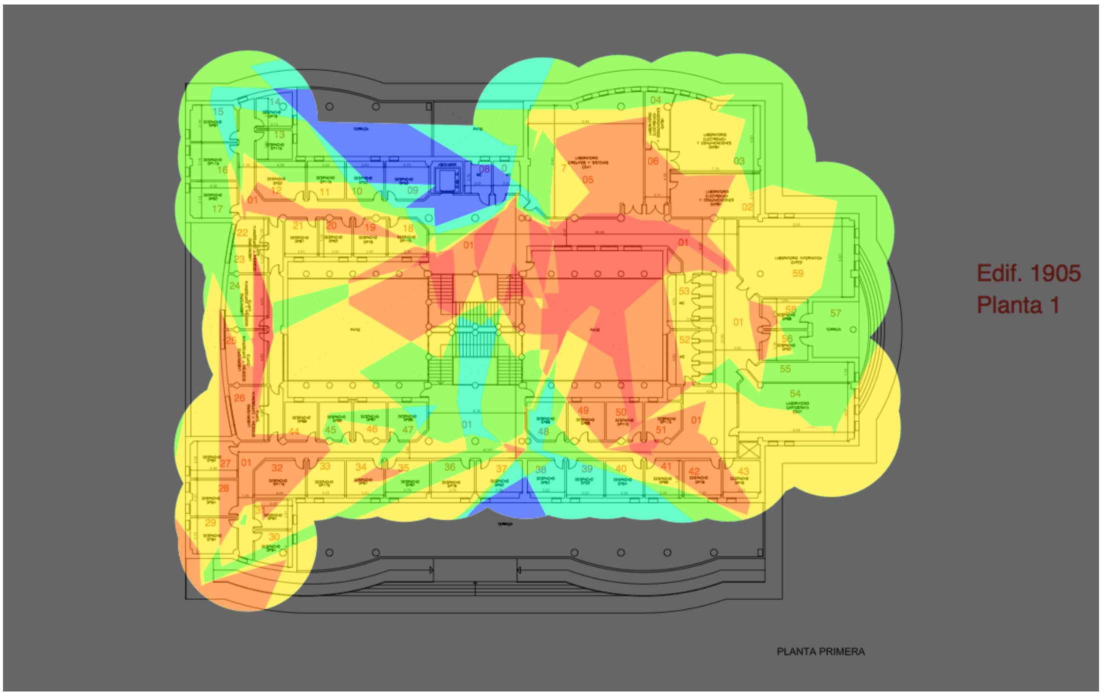
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.2.42.3. Number of Access Points

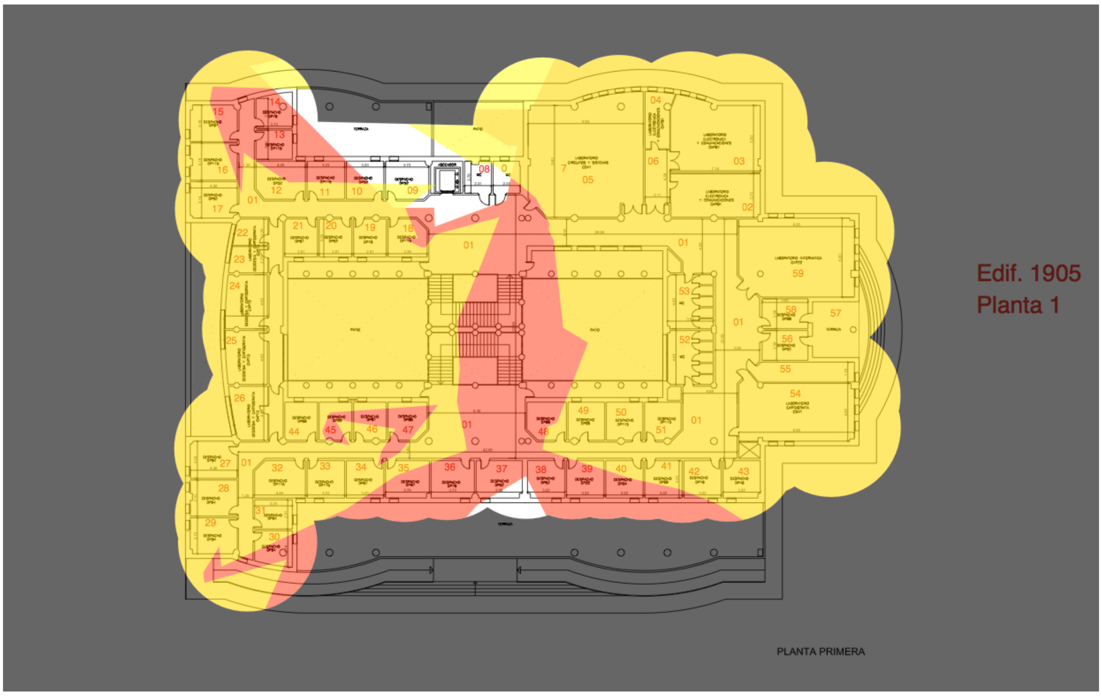


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.42.4. Coverage per Frequency Band



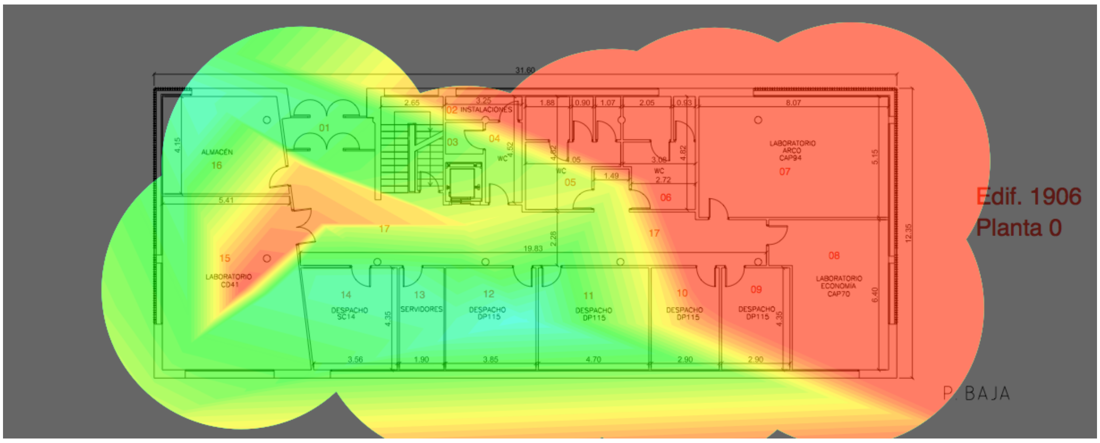
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.2.51. Building 1906 Floor 0

4.2.51.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

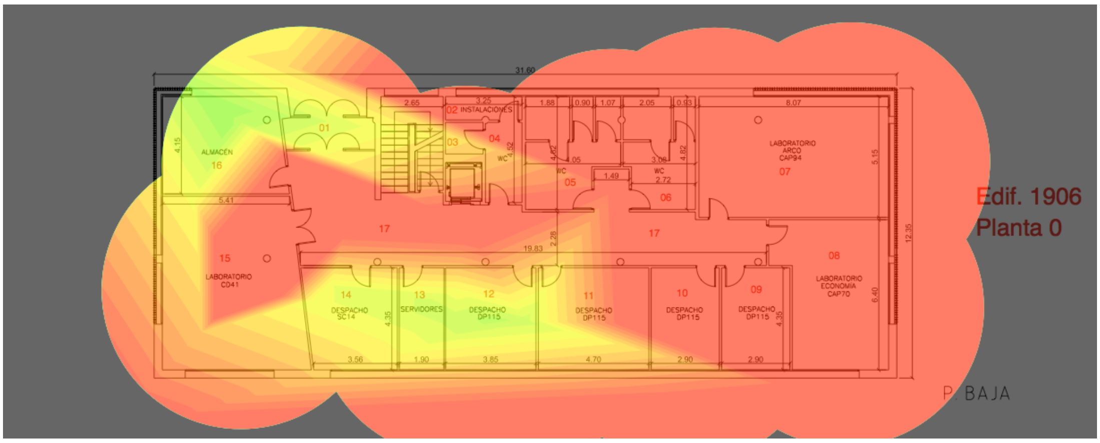


It can be seen that the areas are covered with a good quality signal.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.51.2. Signal Level



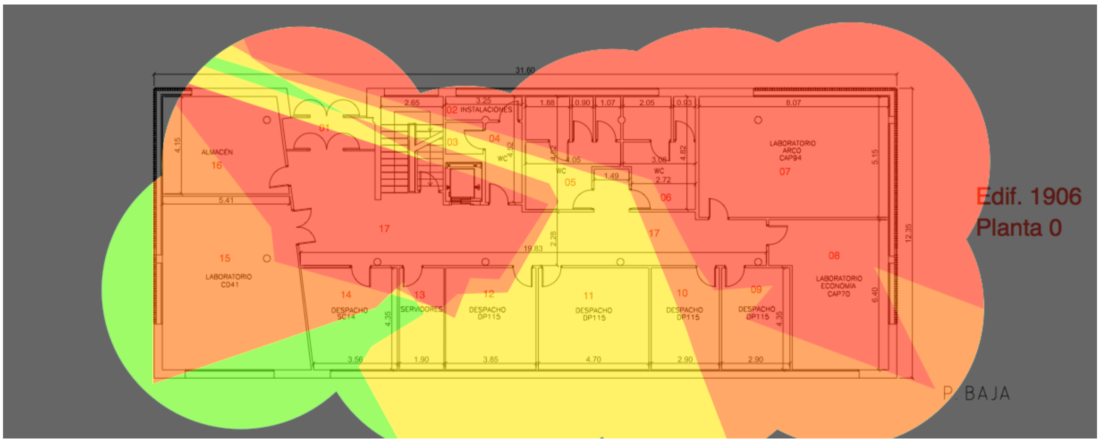
In this picture we can see again how the signal level in the areas are covered with a good intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

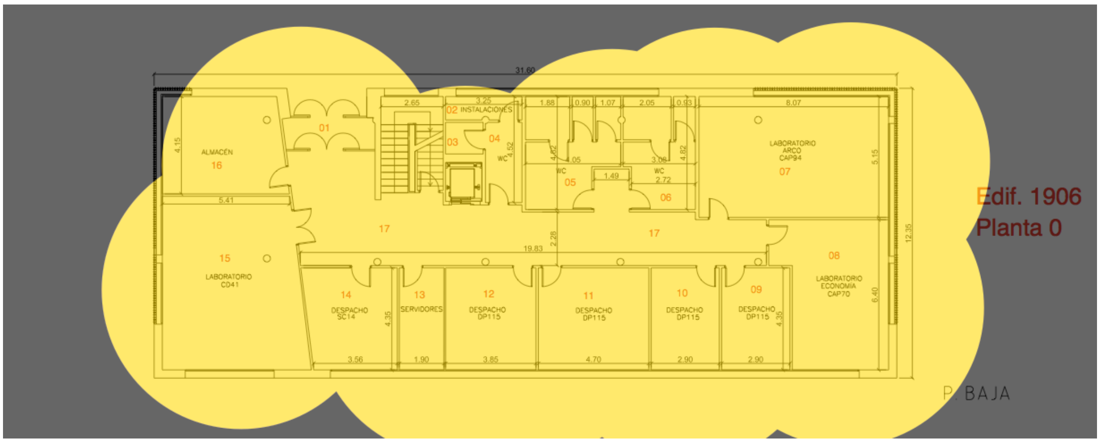
4.2.51.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.51.4. Coverage per Frequency Band

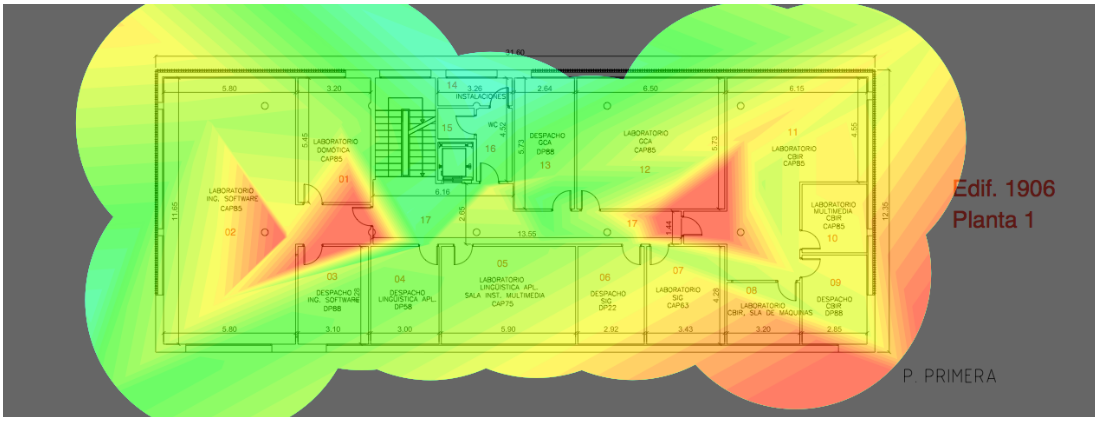


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.2.52. Building 1906 Floor 1

4.2.52.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

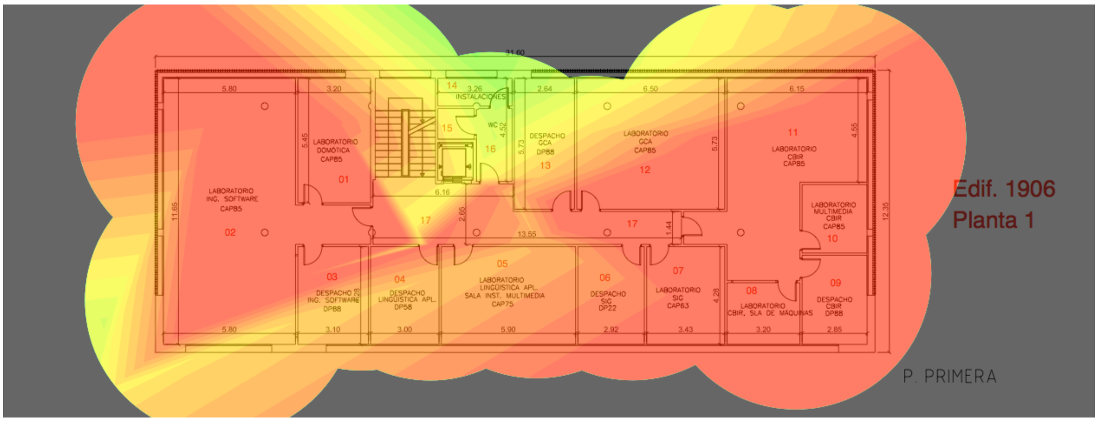


It can be seen that the areas are covered with a good quality signal.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.52.2. Signal Level



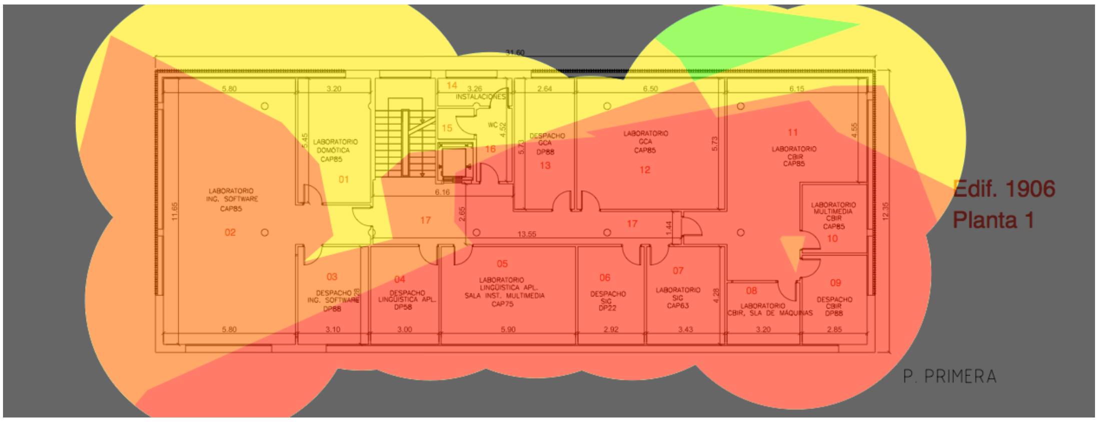
In this picture we can see again how the signal level in the areas are covered with a good intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

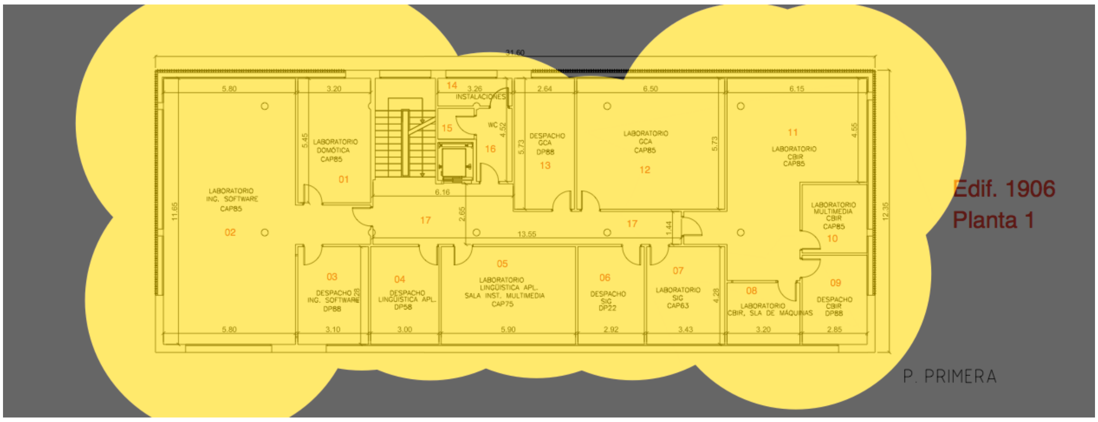
4.2.52.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.52.4. Coverage per Frequency Band

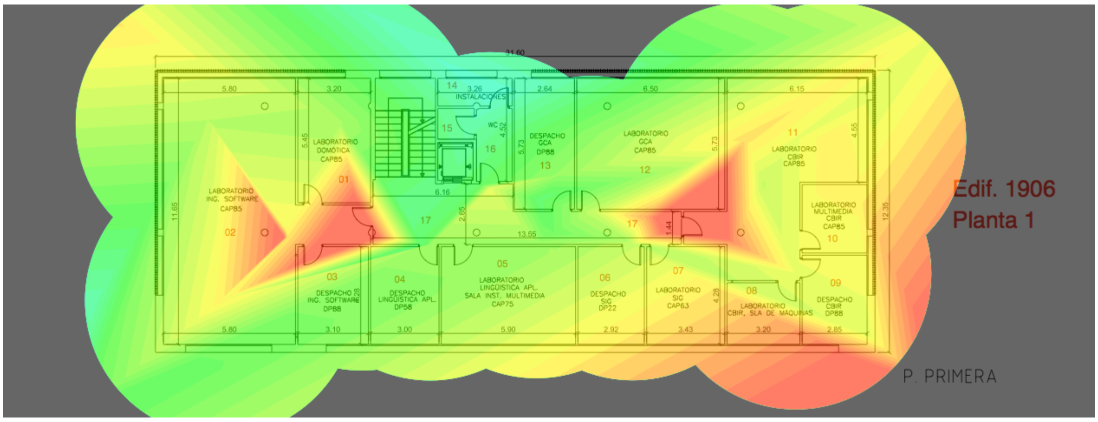


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.2.53. Building 1906 Floor 2

4.2.53.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

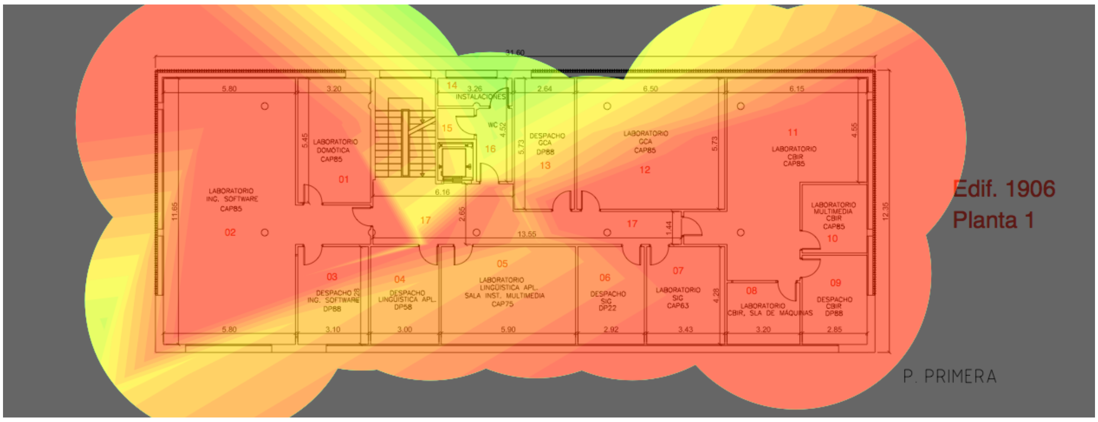


It can be seen that the areas are covered with a good quality signal.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.2.53.2. Signal Level



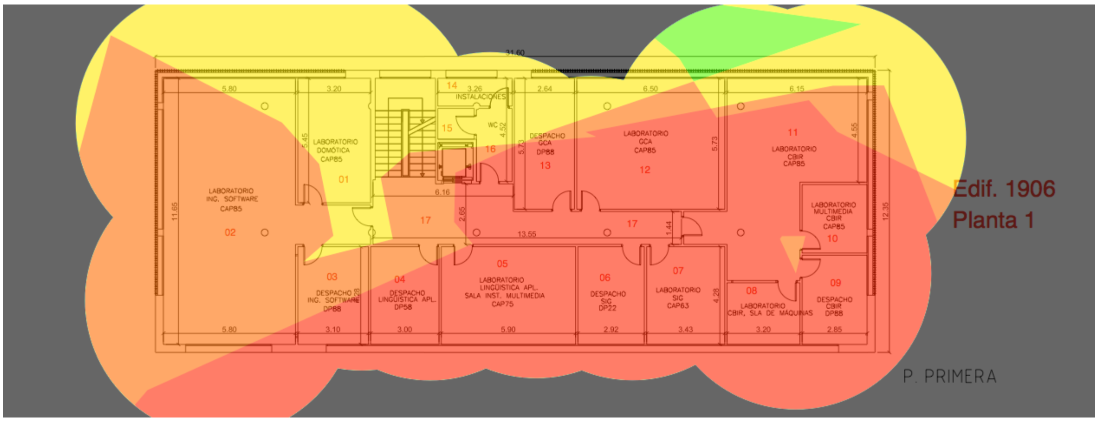
In this picture we can see again how the signal level in the areas are covered with a good intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

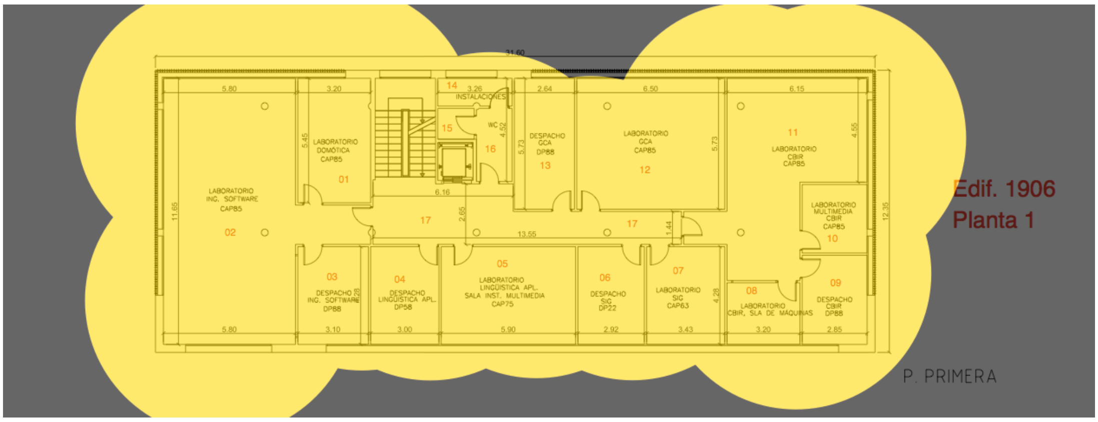
4.2.53.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.2.53.4. Coverage per Frequency Band

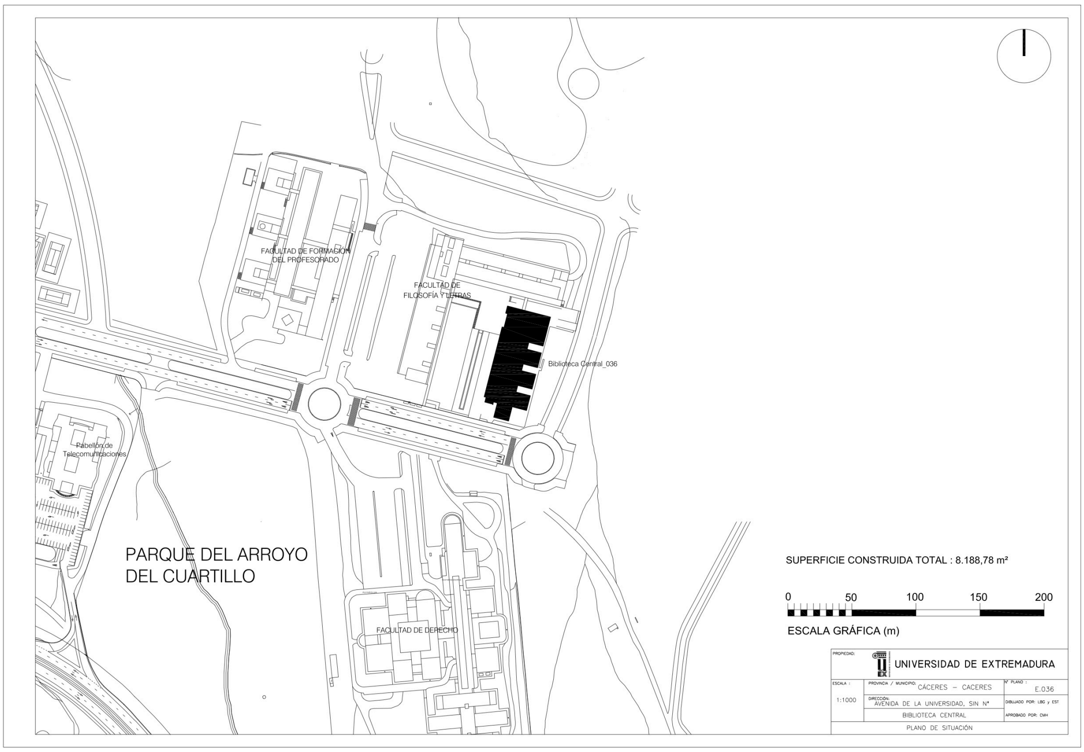


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.3. Biblioteca Central

A total of 192 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

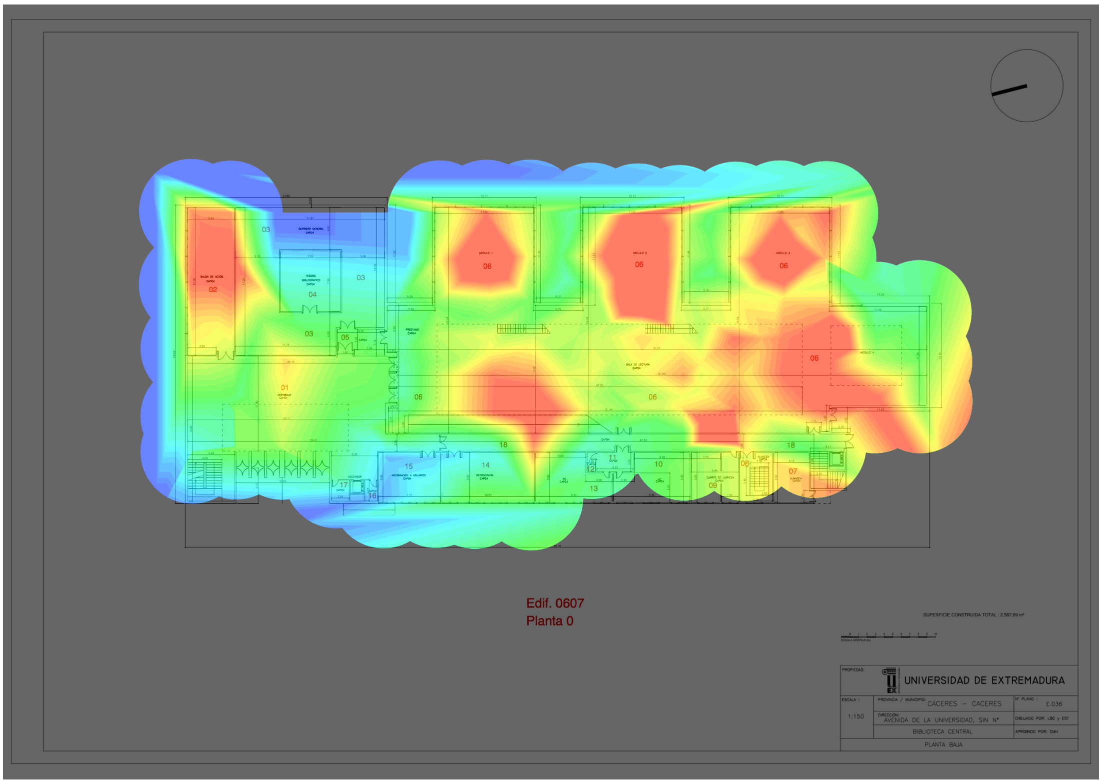
We see the location of the building on the following plan.



4.3.1. Building 0607 Floor 0

4.3.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

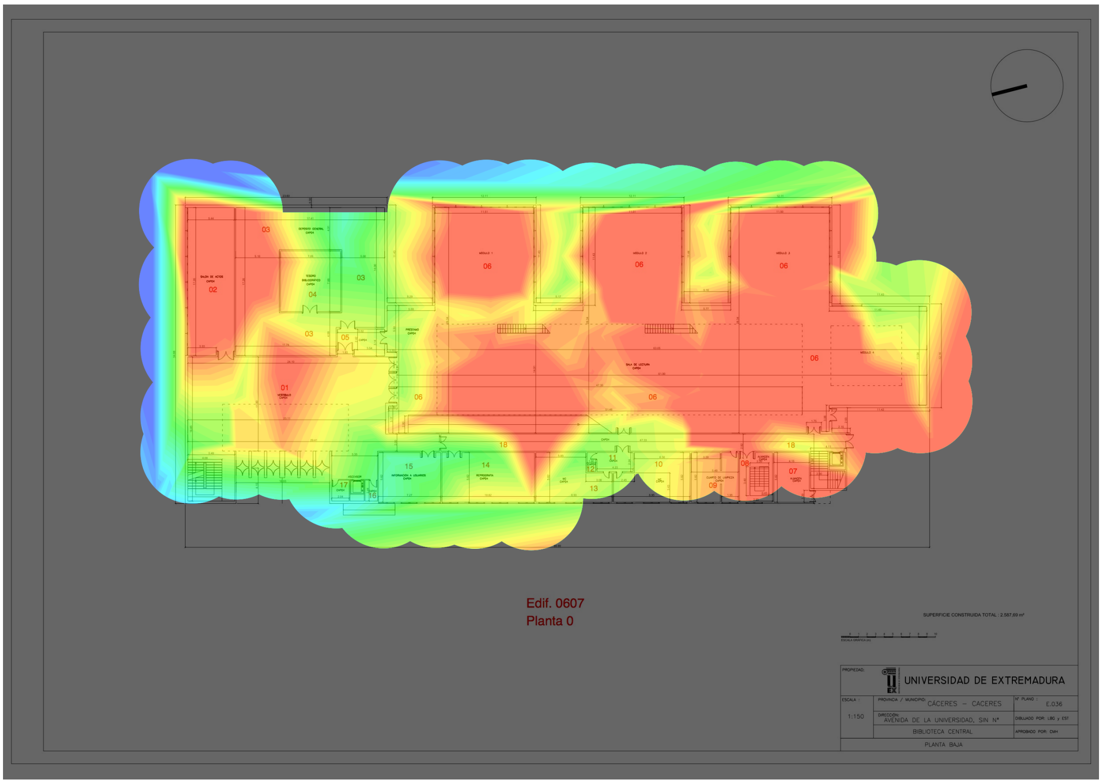


It can be seen that the areas are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.3.1.2. Signal Level



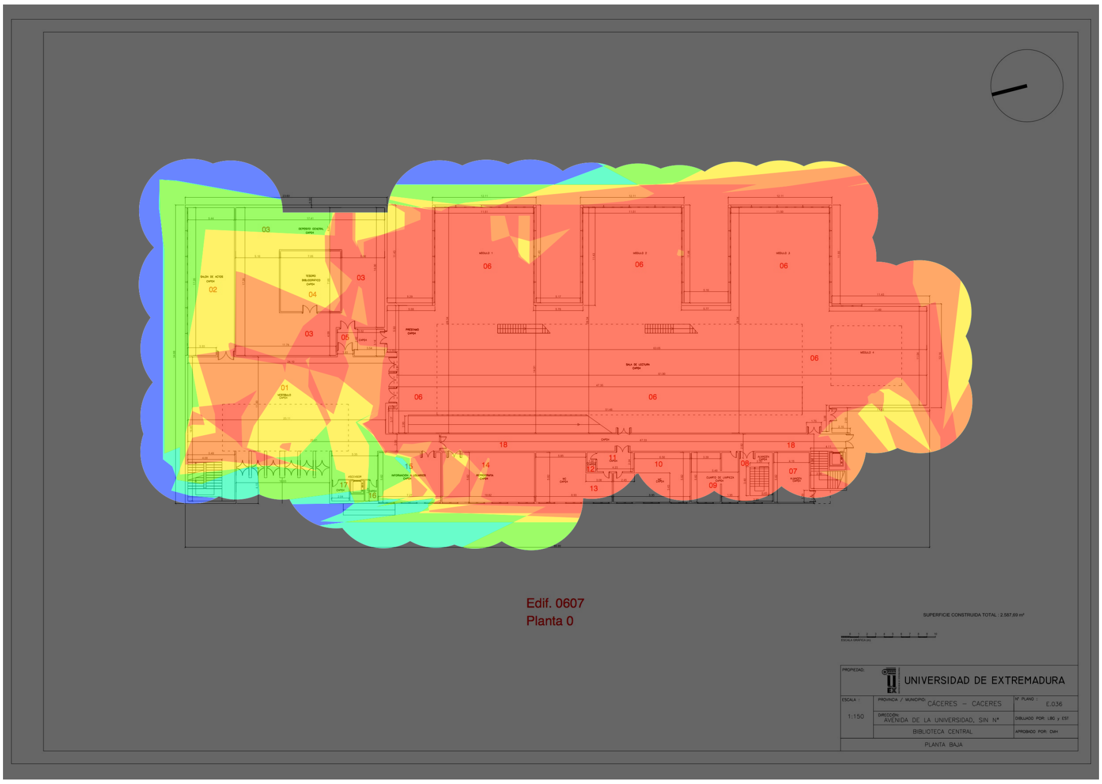
In this picture we can see again how the signal level in the areas of the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.3.1.3. Number of Access Points

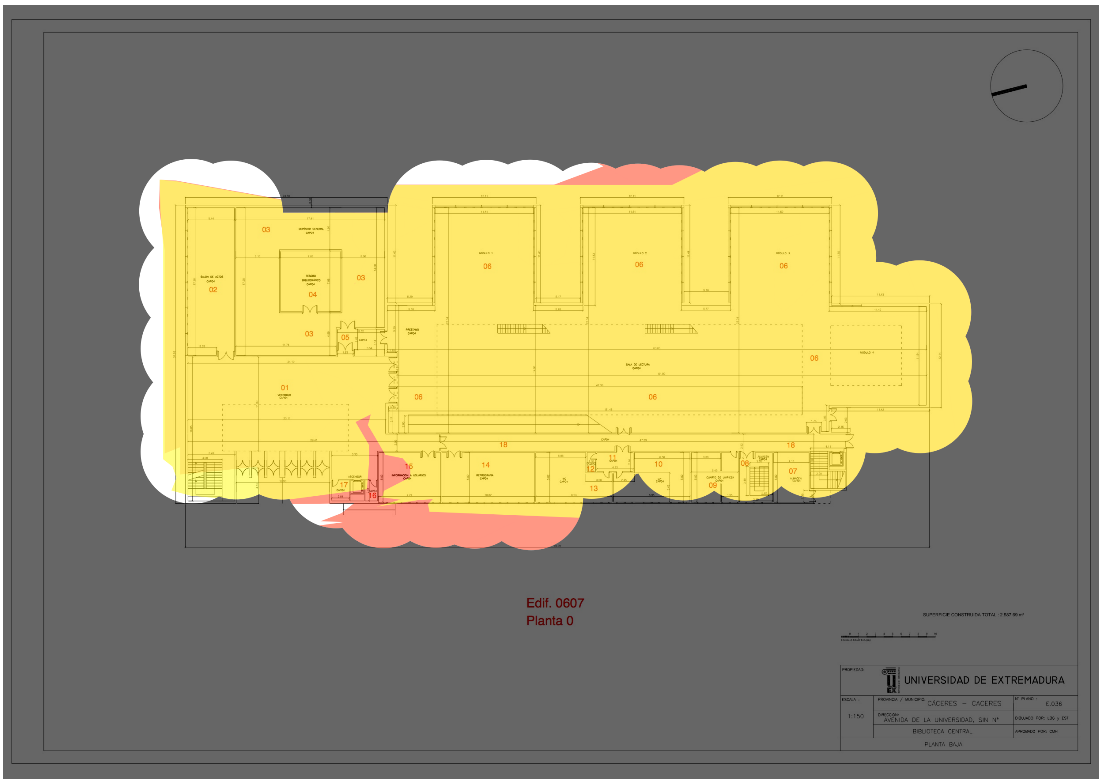


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.3.1.4. Coverage per Frequency Band



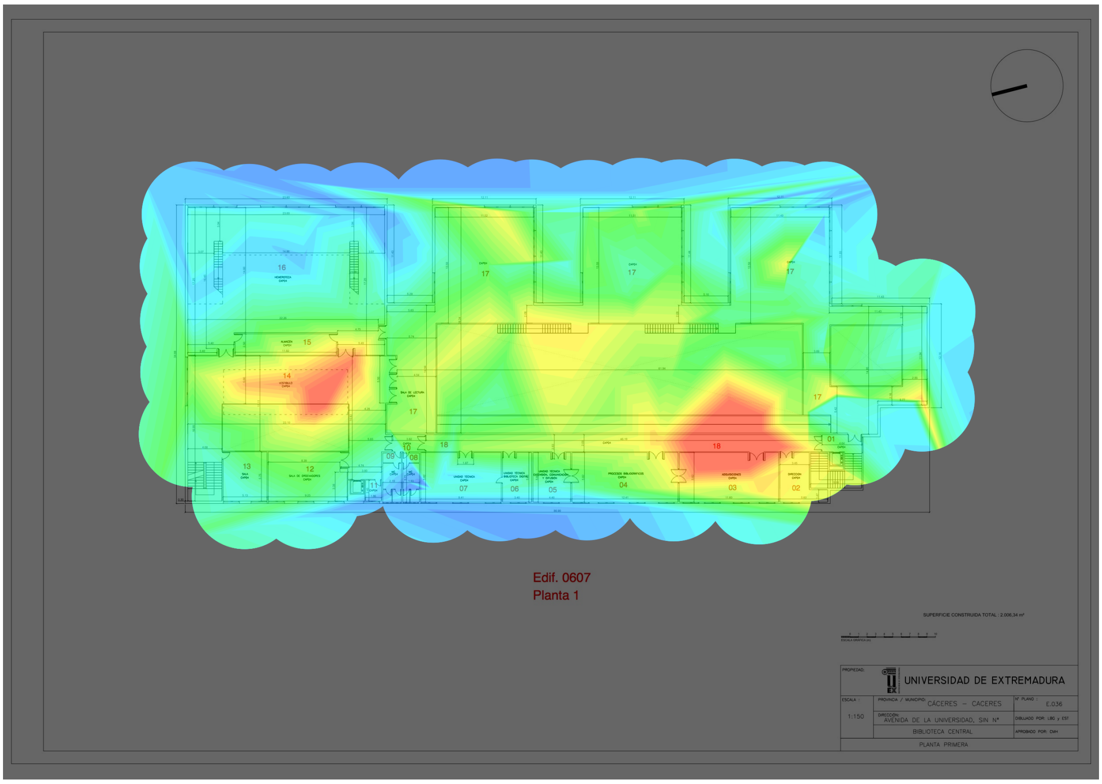
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.3.2. Building 0607 Floor 1

4.3.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

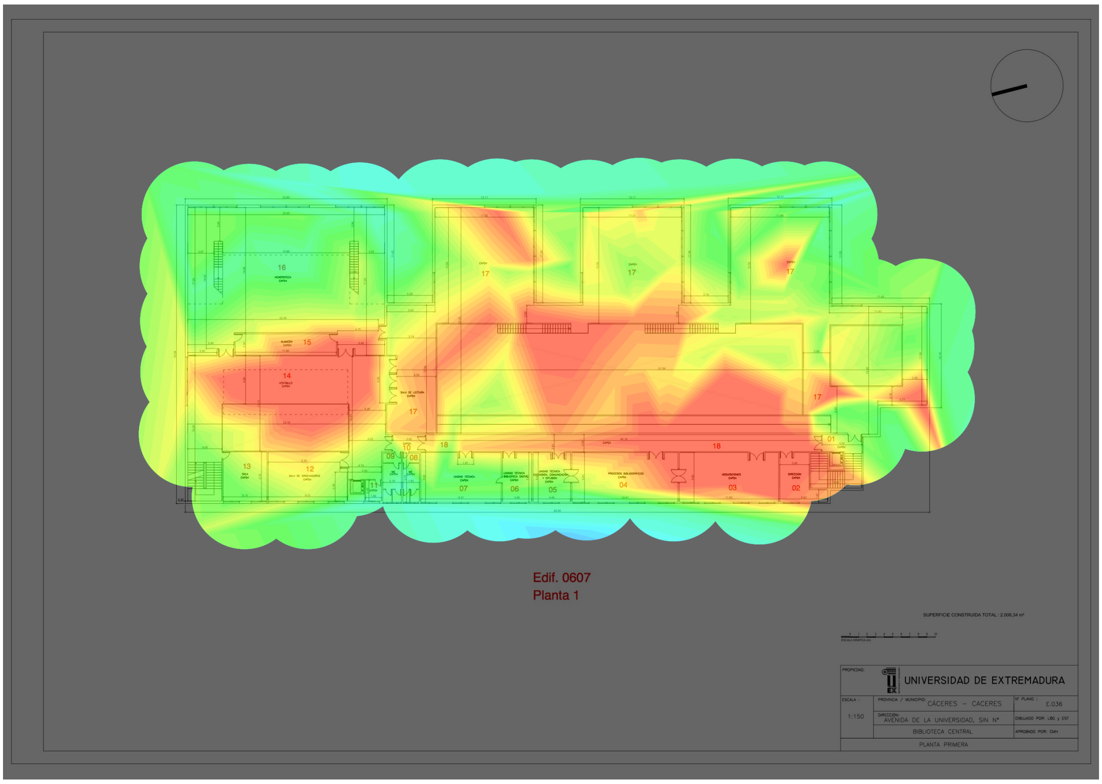


It can be seen that the areas of the library are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.3.2.2. Signal Level



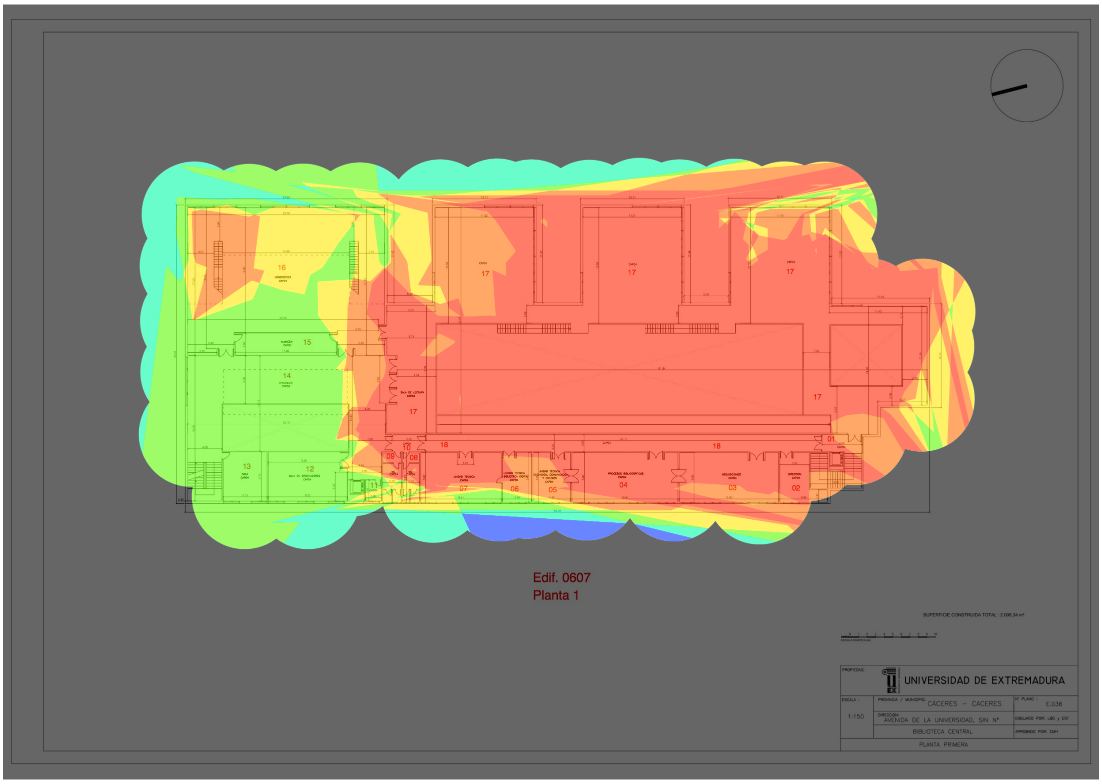
In this picture we can see again how the signal level in the areas of the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.3.2.3. Number of Access Points

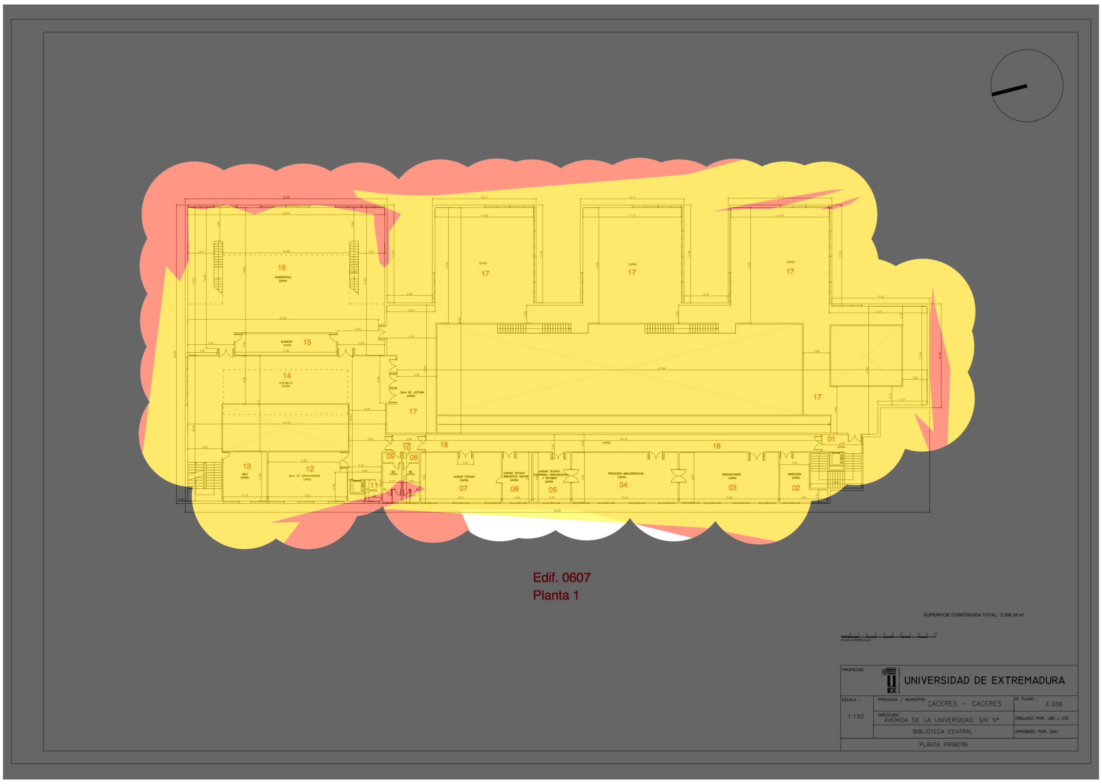


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.3.2.4 Coverage per Frequency Band



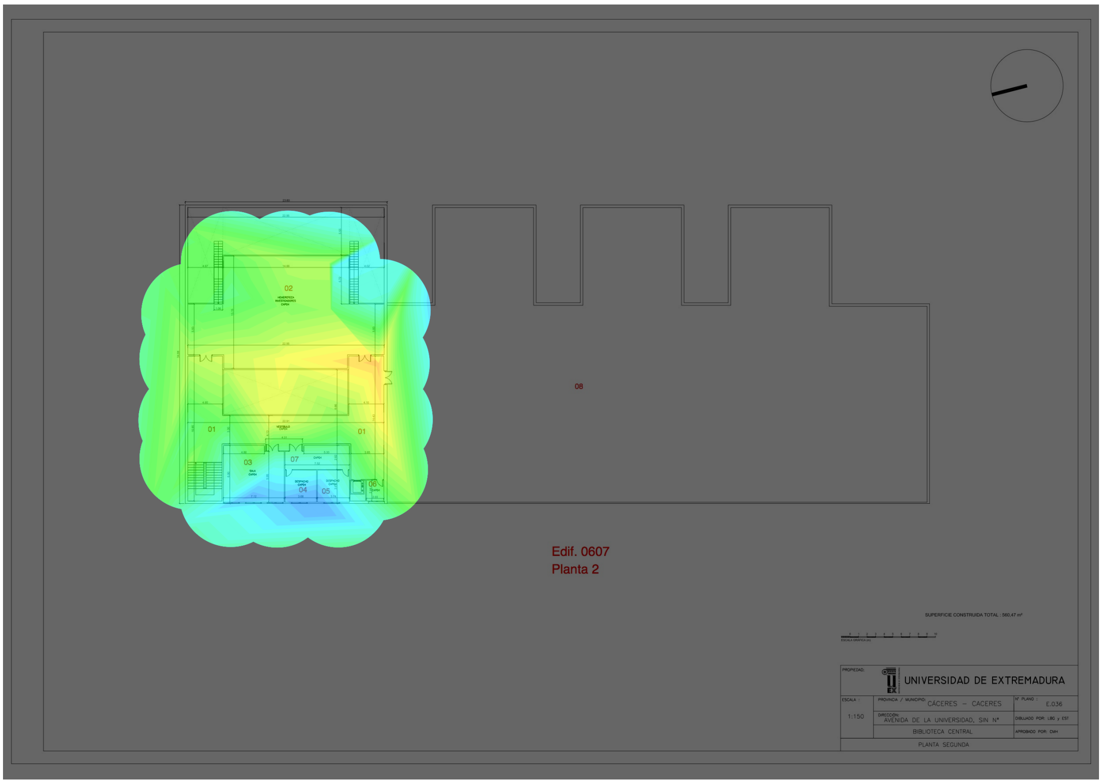
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.3.3. Building 0607 Floor 2

4.3.3.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

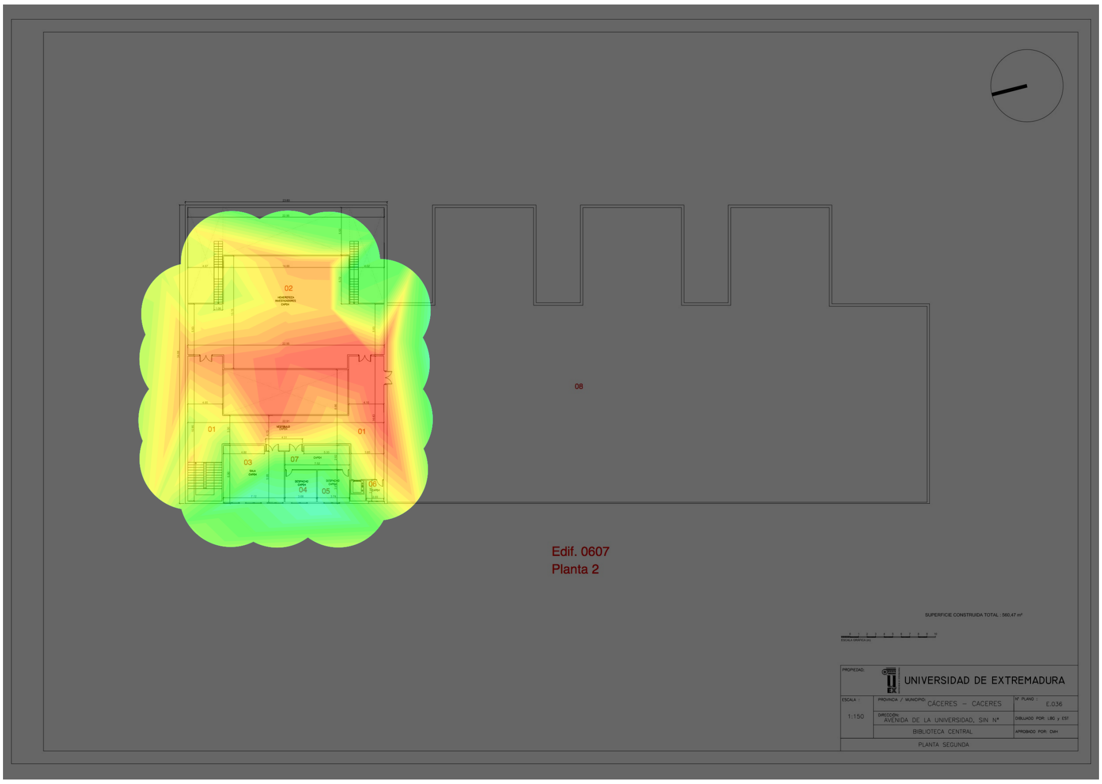


It can be seen that the areas of the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.3.3.2. Signal Level



In this picture we can see again how the signal level in the areas are covered with a good intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

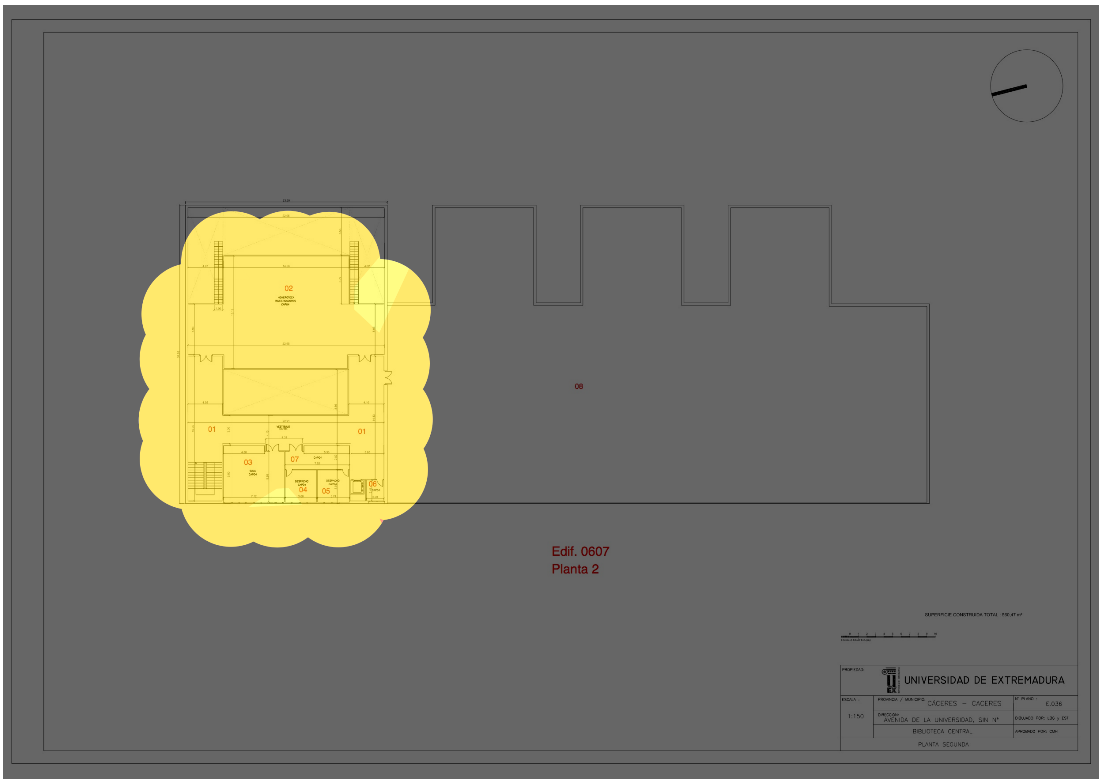
4.3.3.3. Number of Access Points

In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.3.3.4. Coverage per Frequency Band

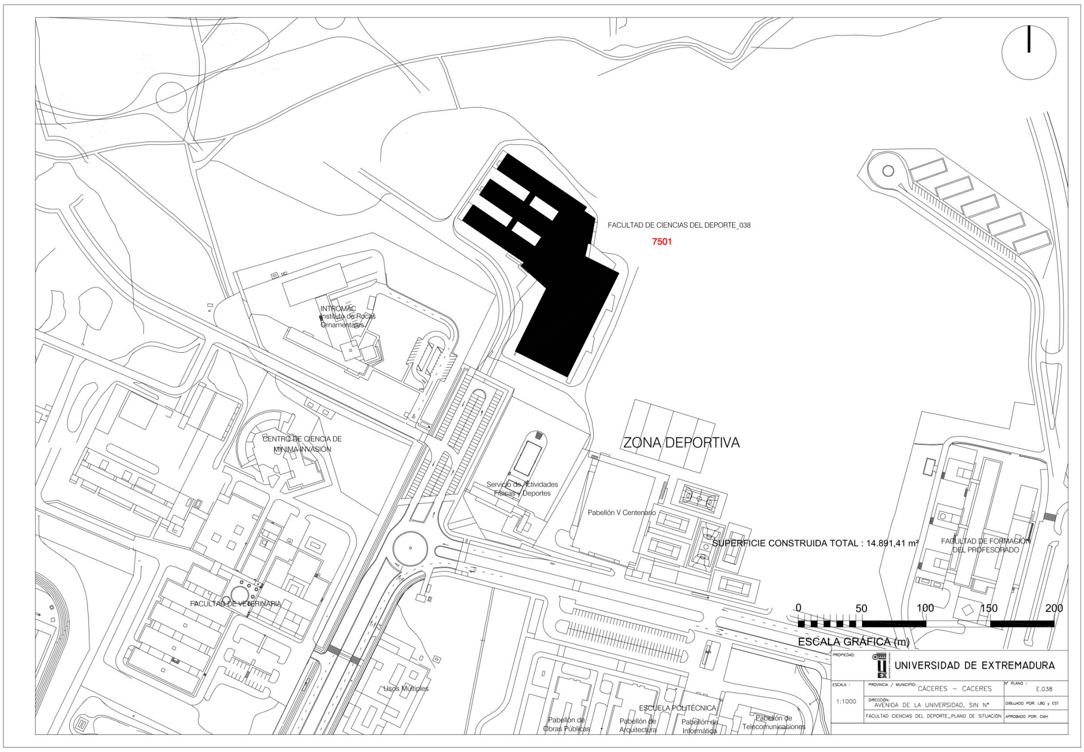


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.4. Facultad de Ciencias del Deporte

A total of 329 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

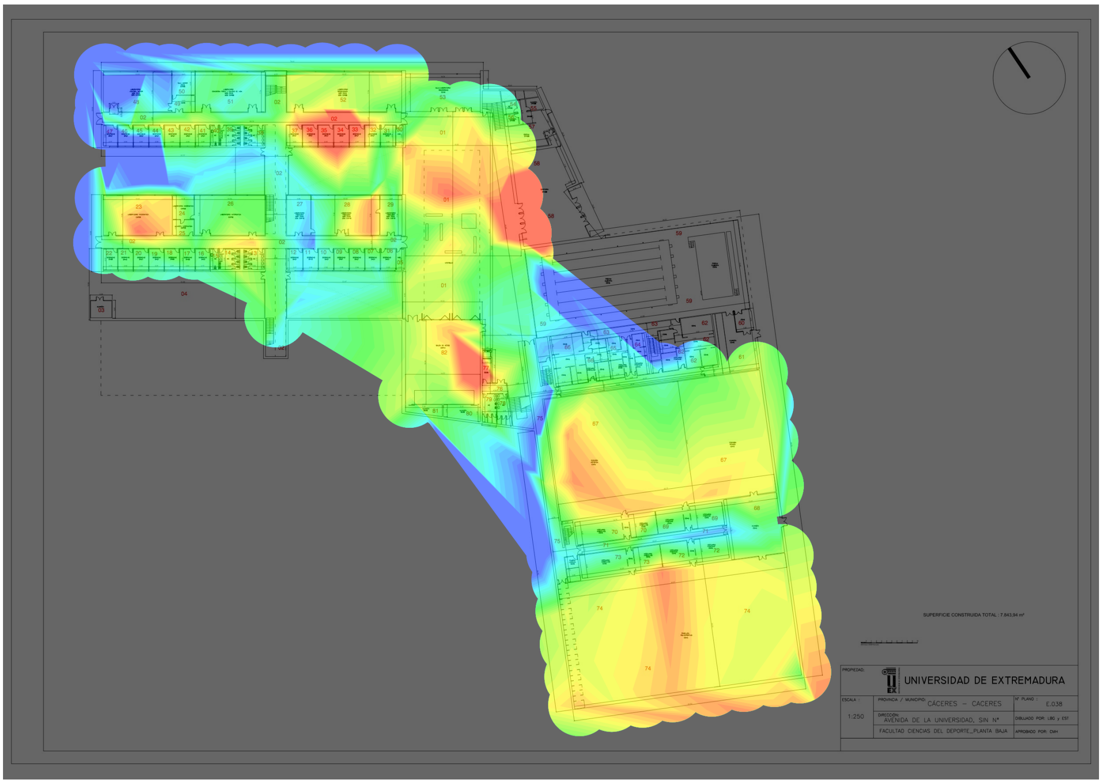
We see the location of the building on the following plan.



4.4.1. Building 7501 Floor 0

4.4.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

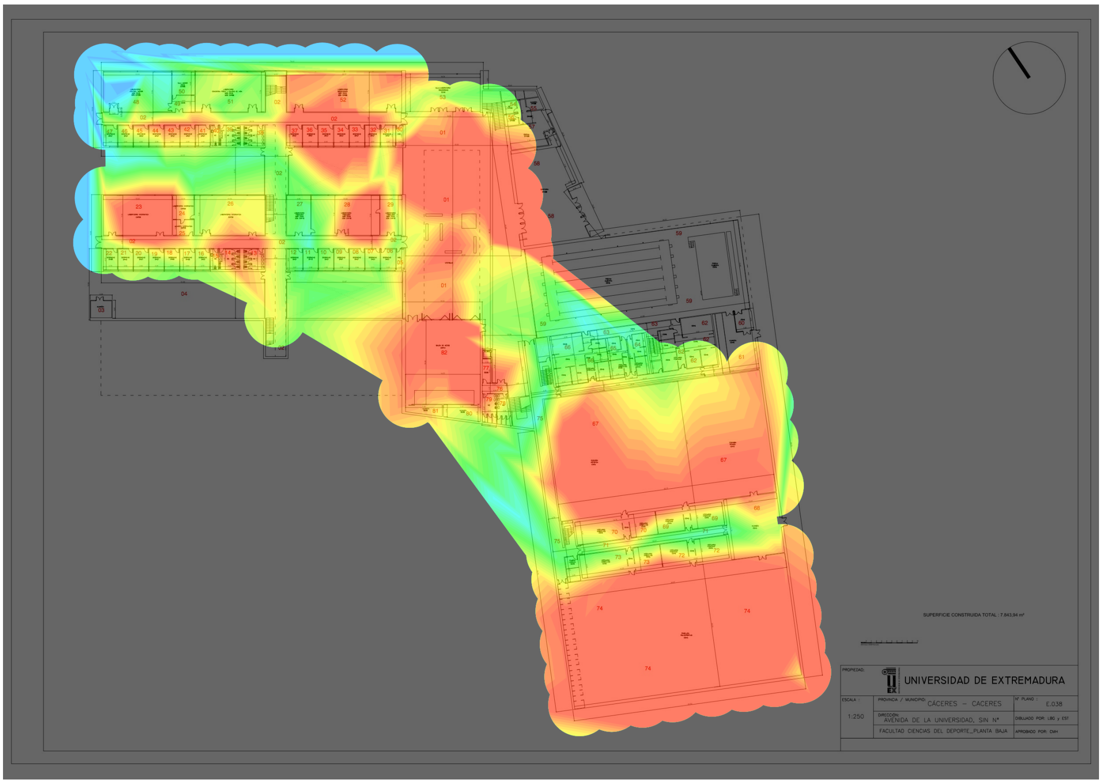


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.4.1.2. Signal Level



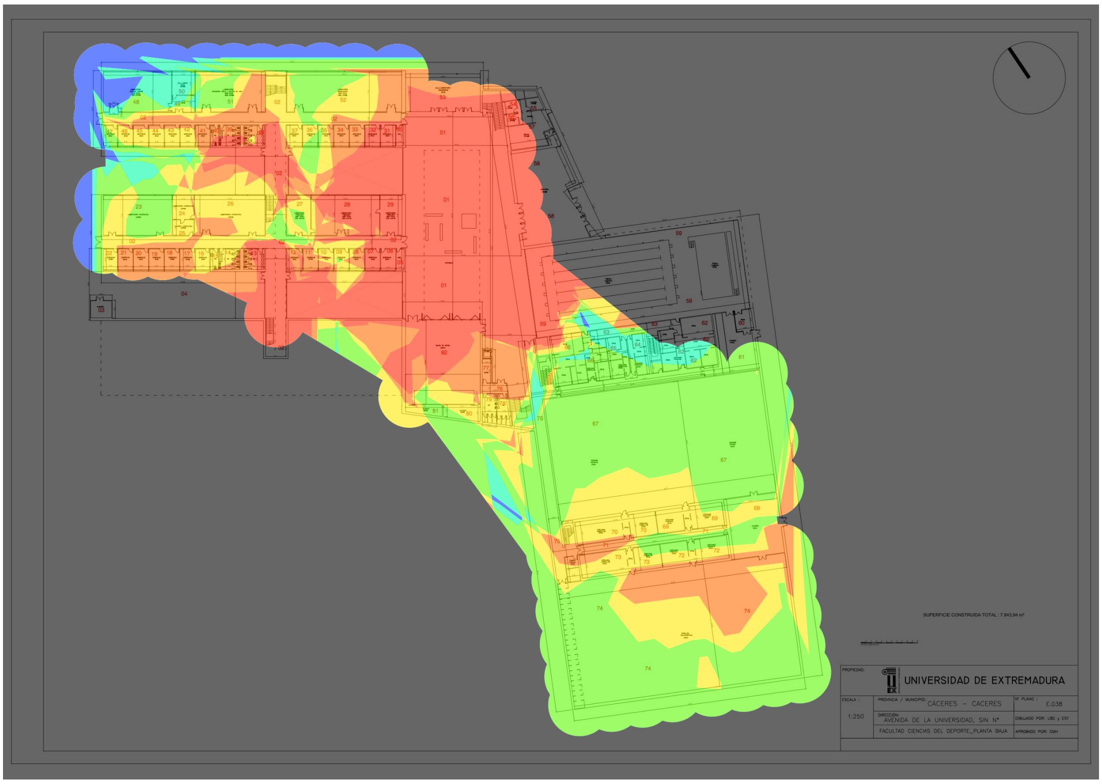
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.4.1.3. Number of Access Points

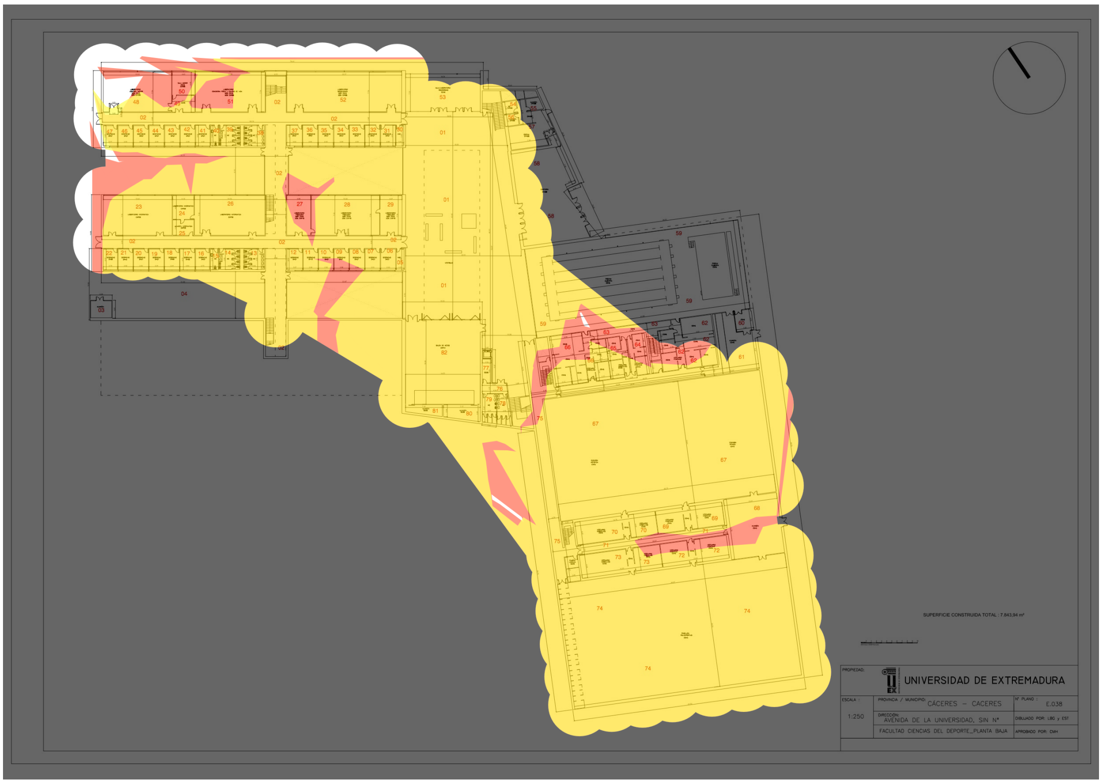


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.4.1.4. Coverage per Frequency Band



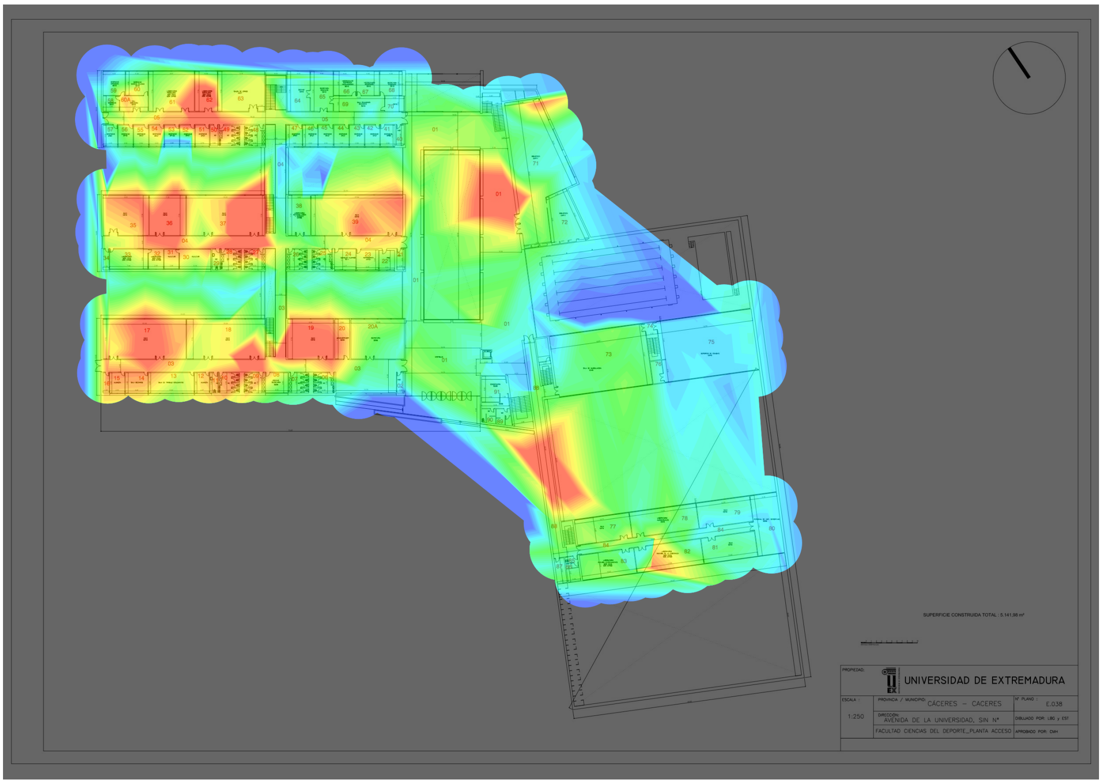
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.4.2. Building 7501 Floor 1

4.4.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

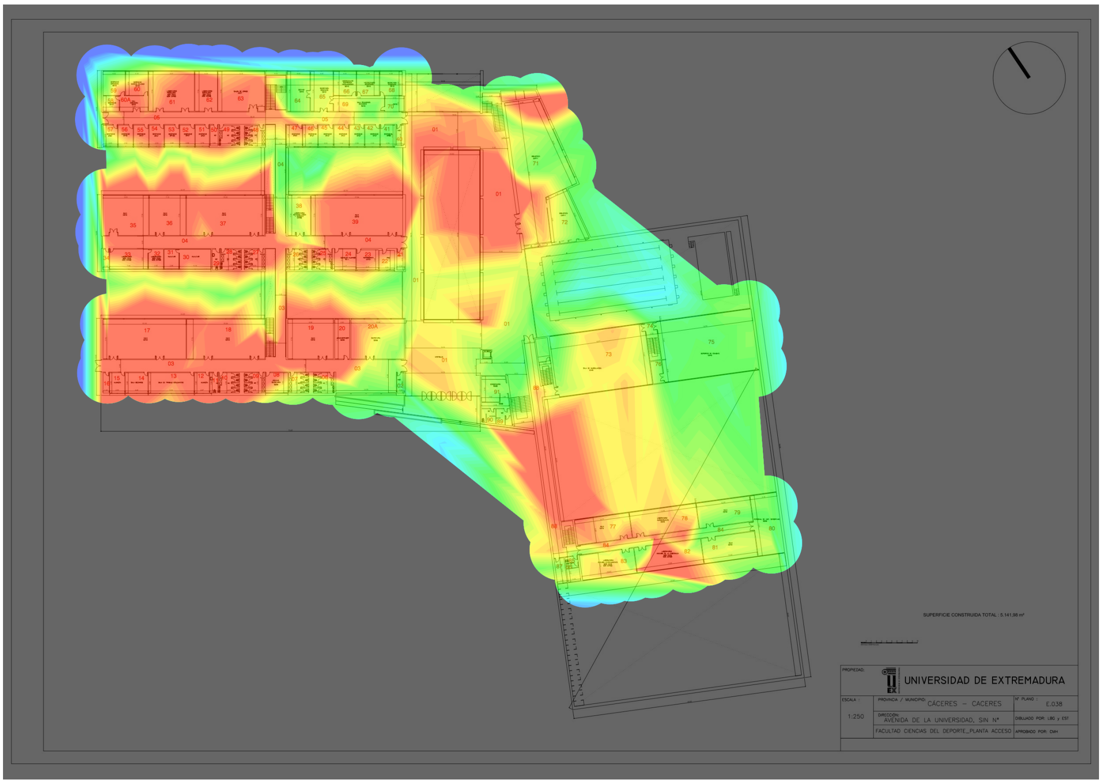


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.4.2.2. Signal Level



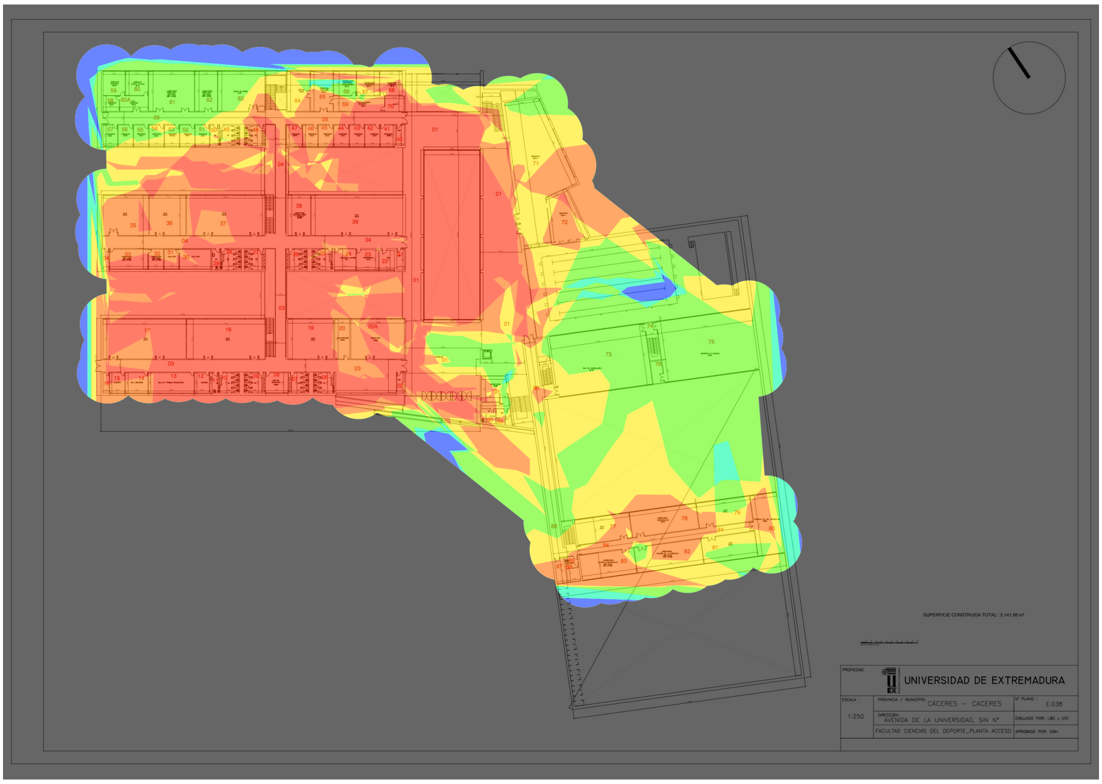
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.4.2.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.4.2.4. Coverage per Frequency Band

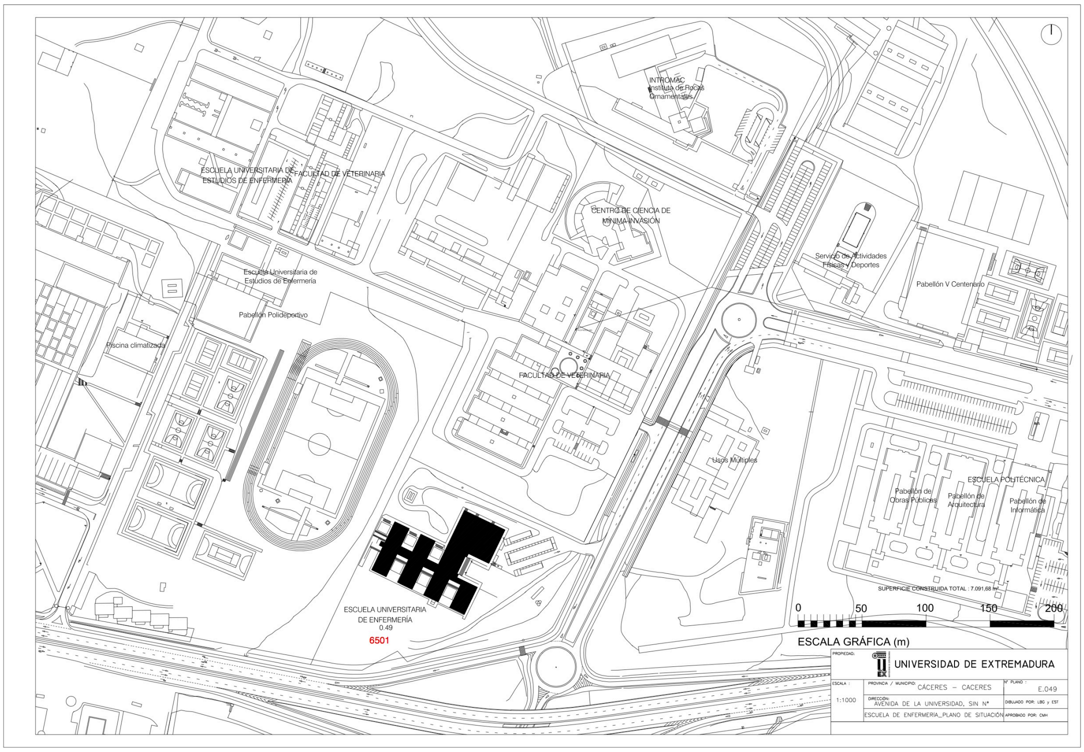
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.5. Facultad de Enfermería y Terapia Ocupacional

A total of 273 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

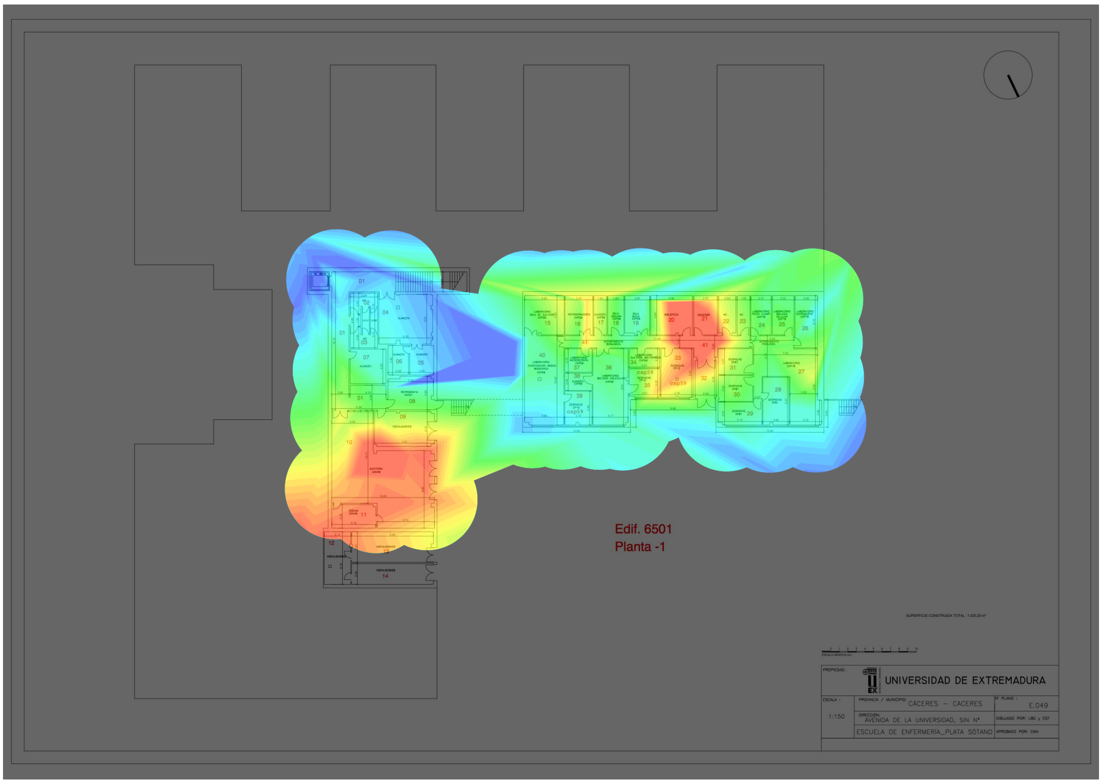
We see the location of the buildings on the following plan.



4.5.1. Building 6501 Floor -1

4.5.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

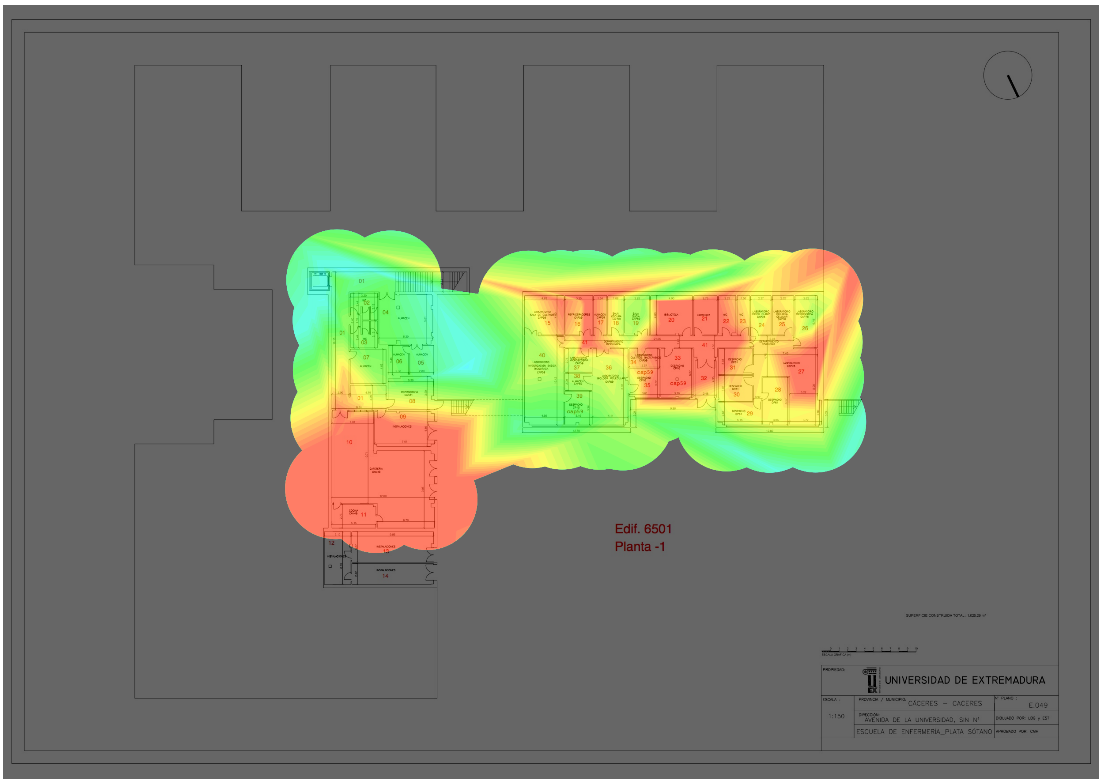


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.5.1.2. Signal Level



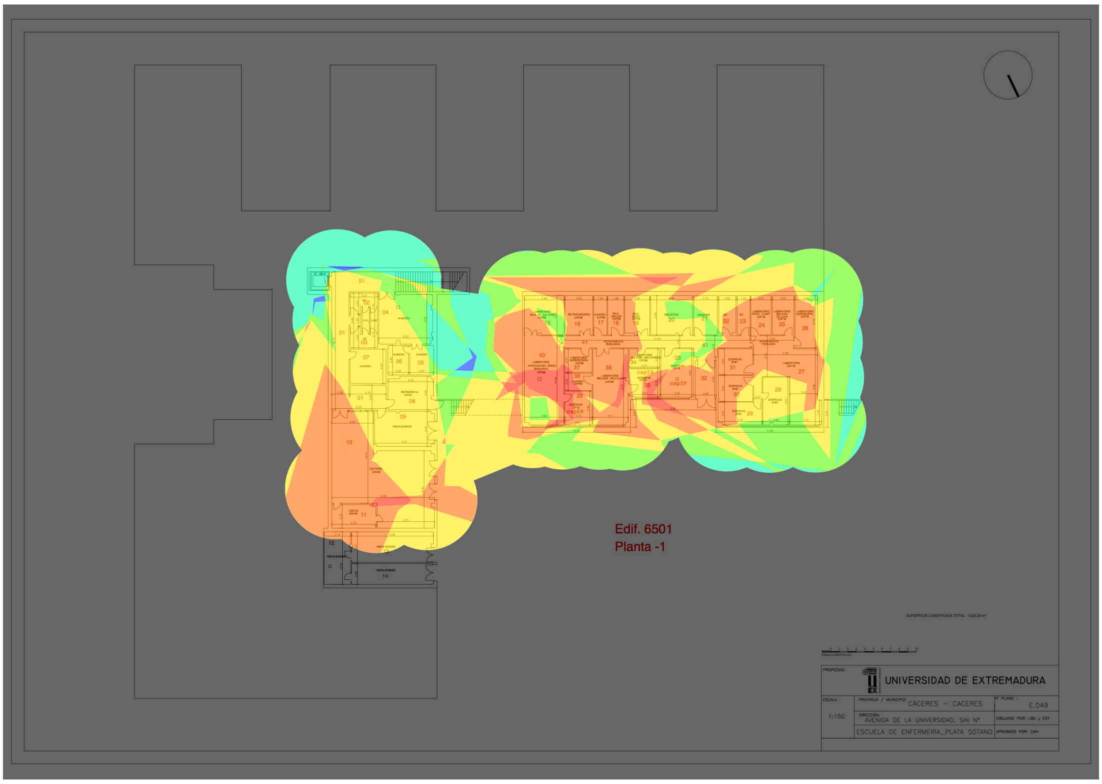
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.5.1.3. Number of Access Points

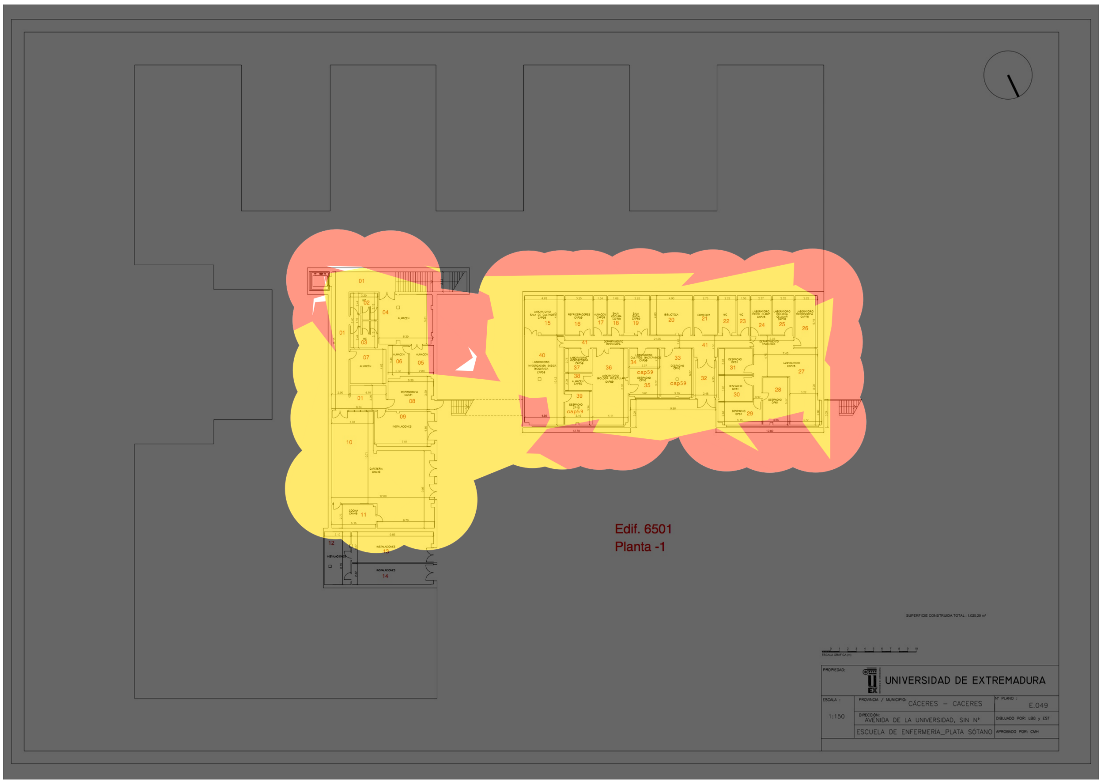


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.5.1.4. Coverage per Frequency Band



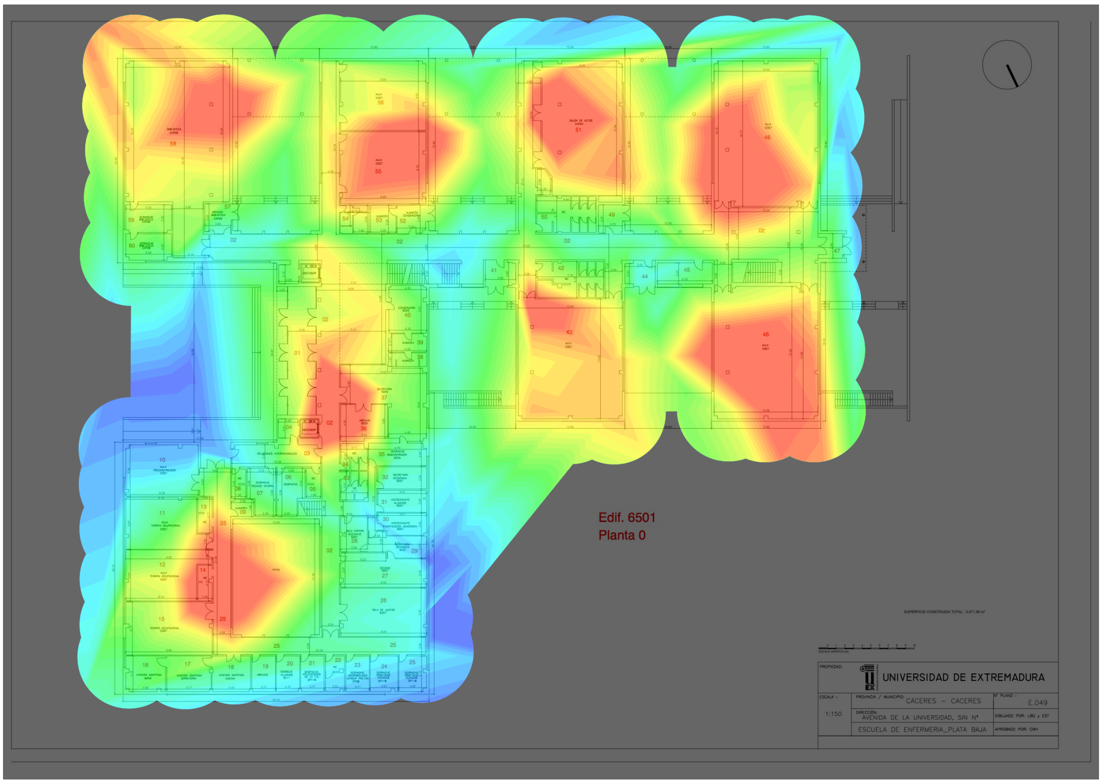
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.5.2. Building 6501 Floor 0

4.5.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

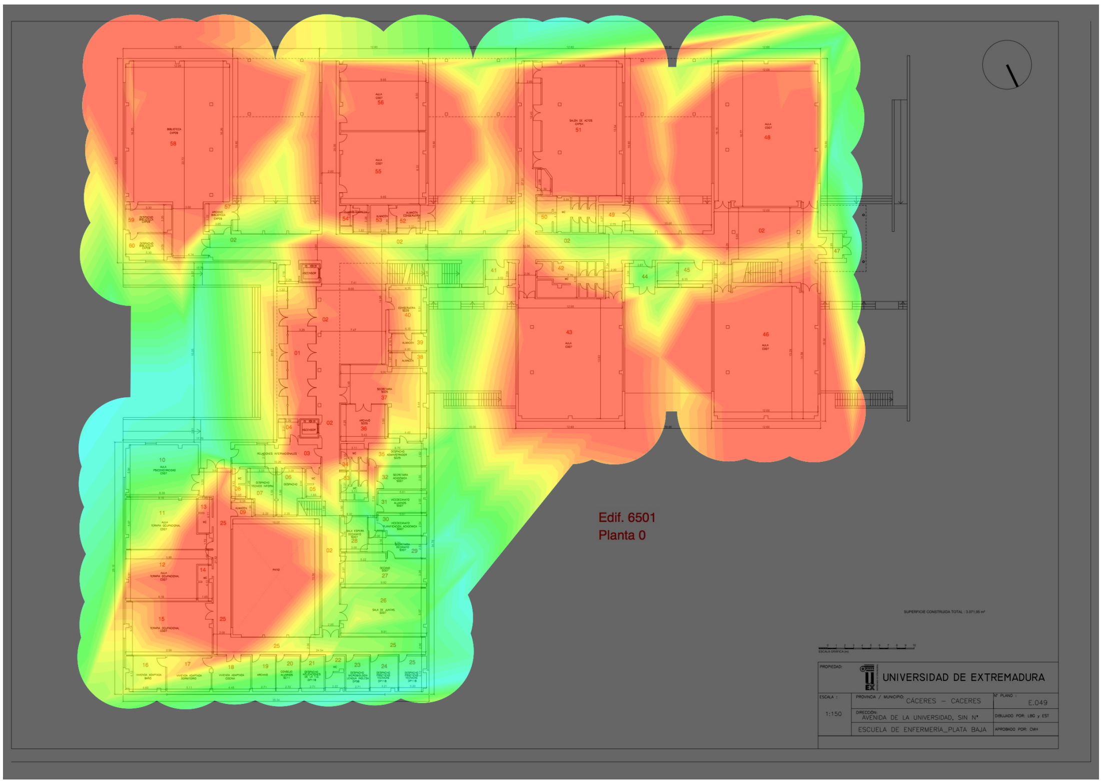


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.5.2.2. Signal Level



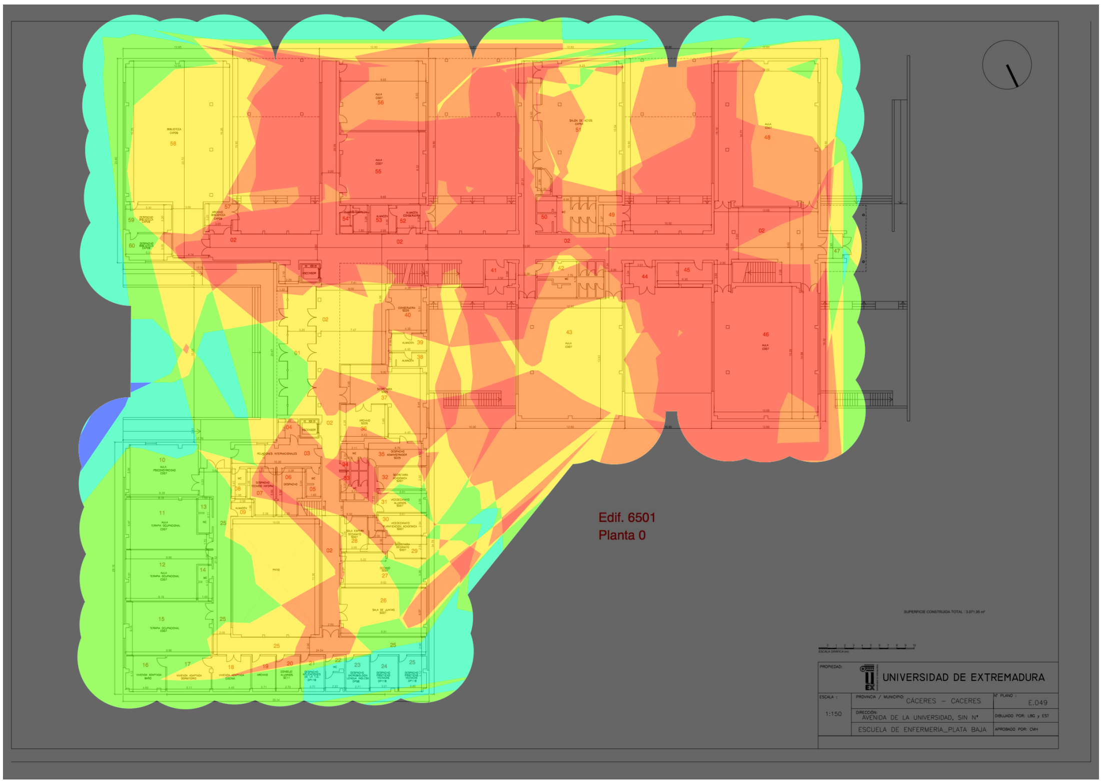
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.5.2.3. Number of Access Points

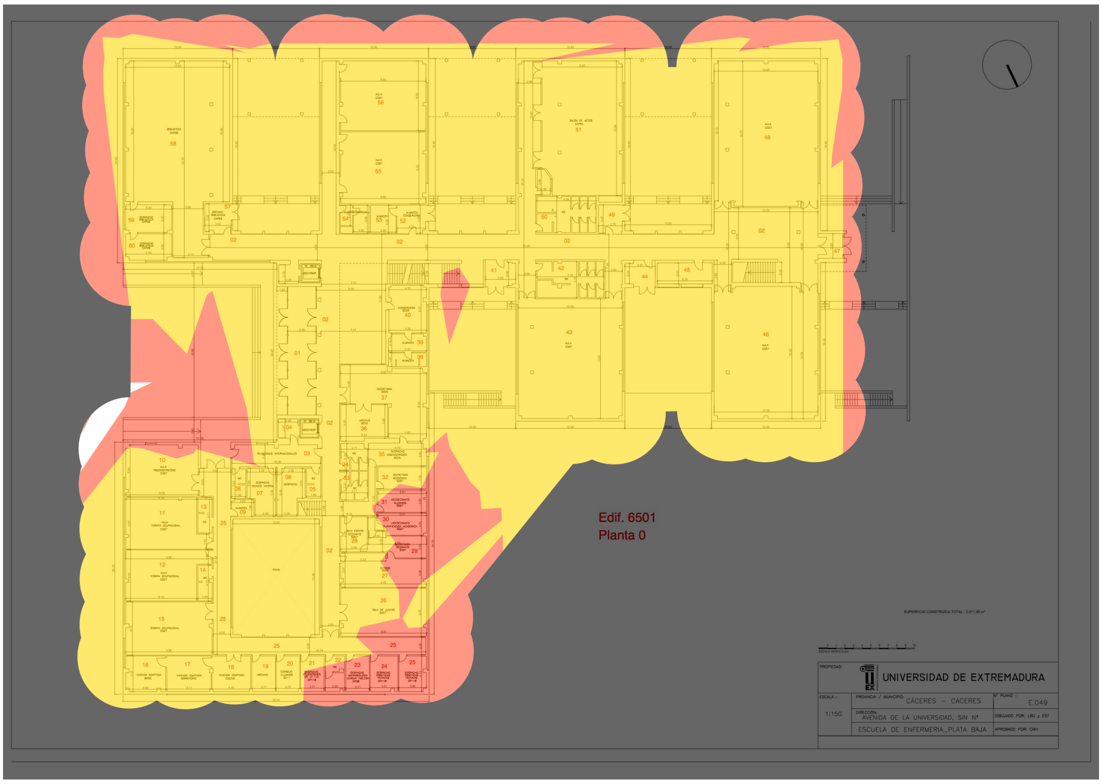


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.5.2.4. Coverage per Frequency Band



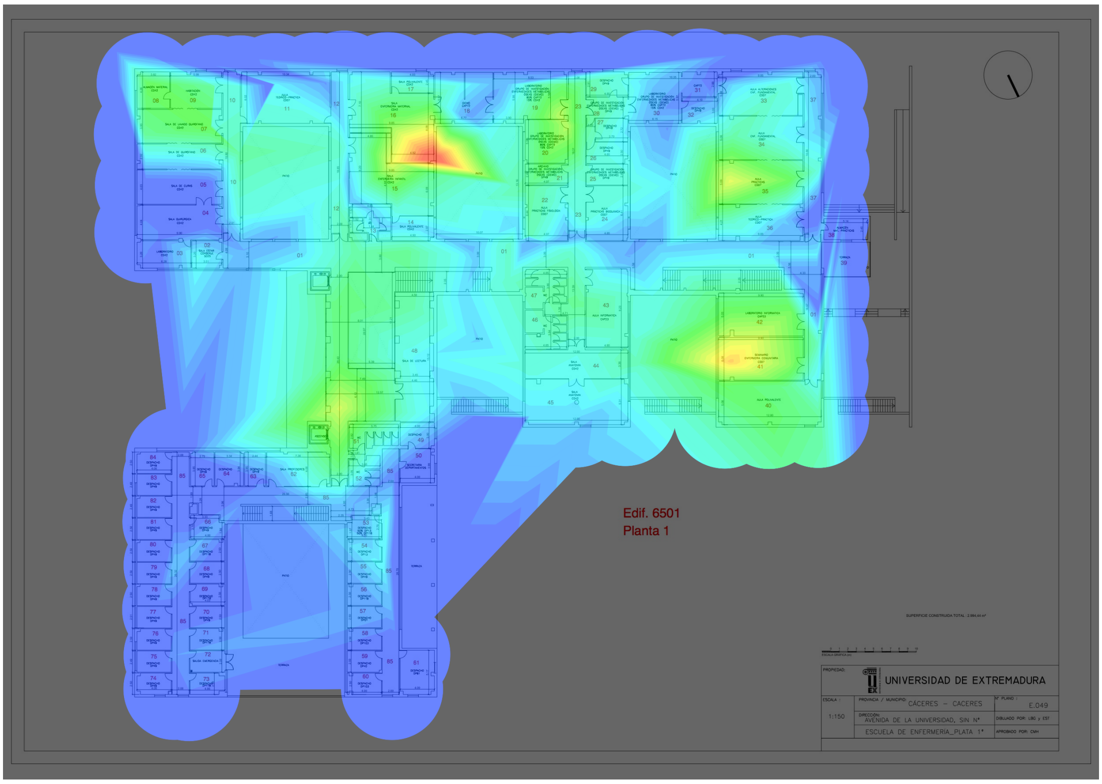
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.5.3. Building 6501 Floor 1

4.5.3.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

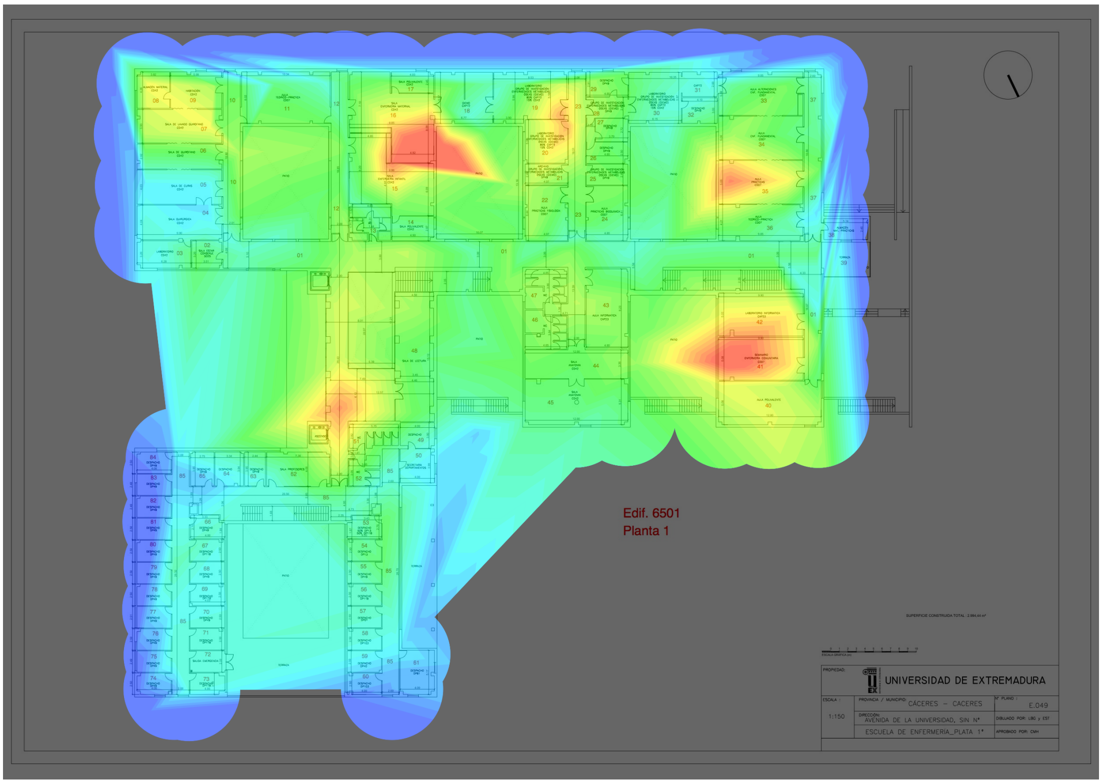


It can be seen that the areas where the classrooms are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.5.3.2. Signal Level



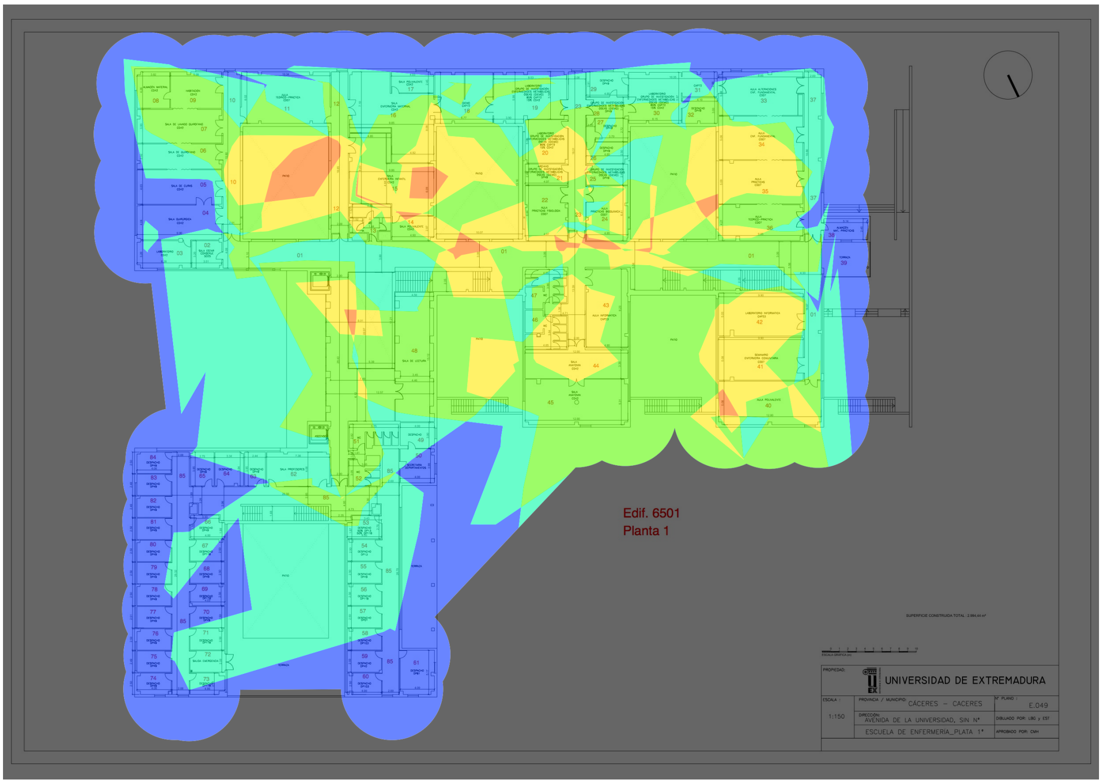
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.5.3.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.5.3.4. Coverage per Frequency Band

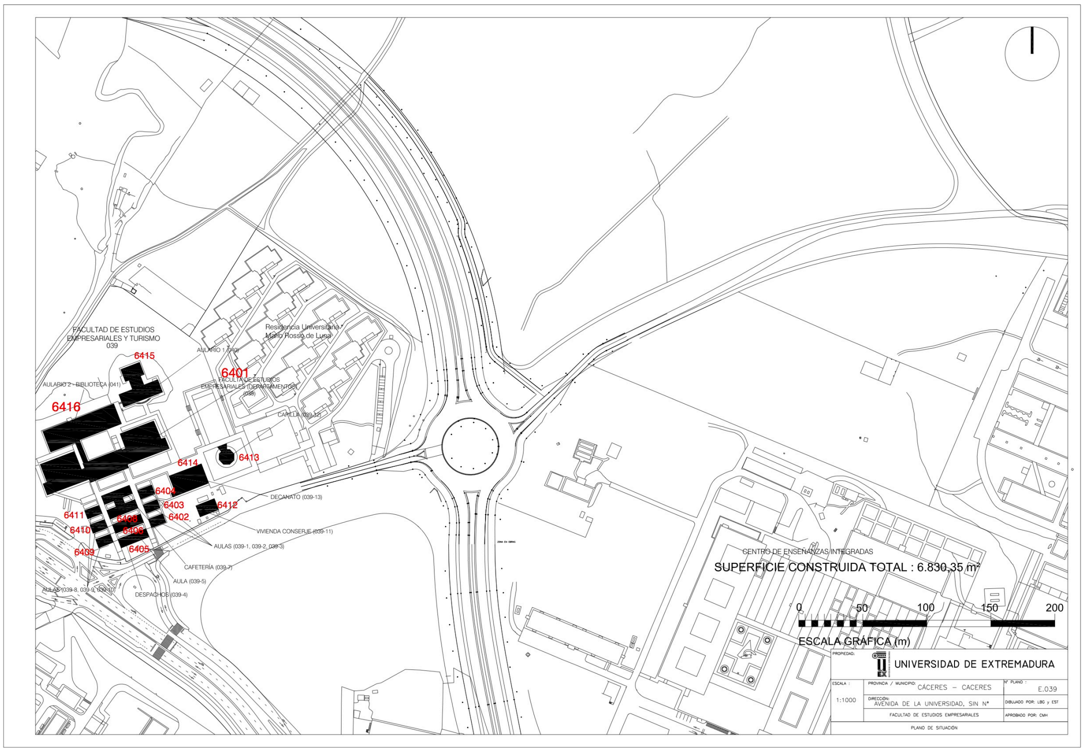
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.6. Facultad de Estudios Empresariales y Turismo.

A total of 278 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

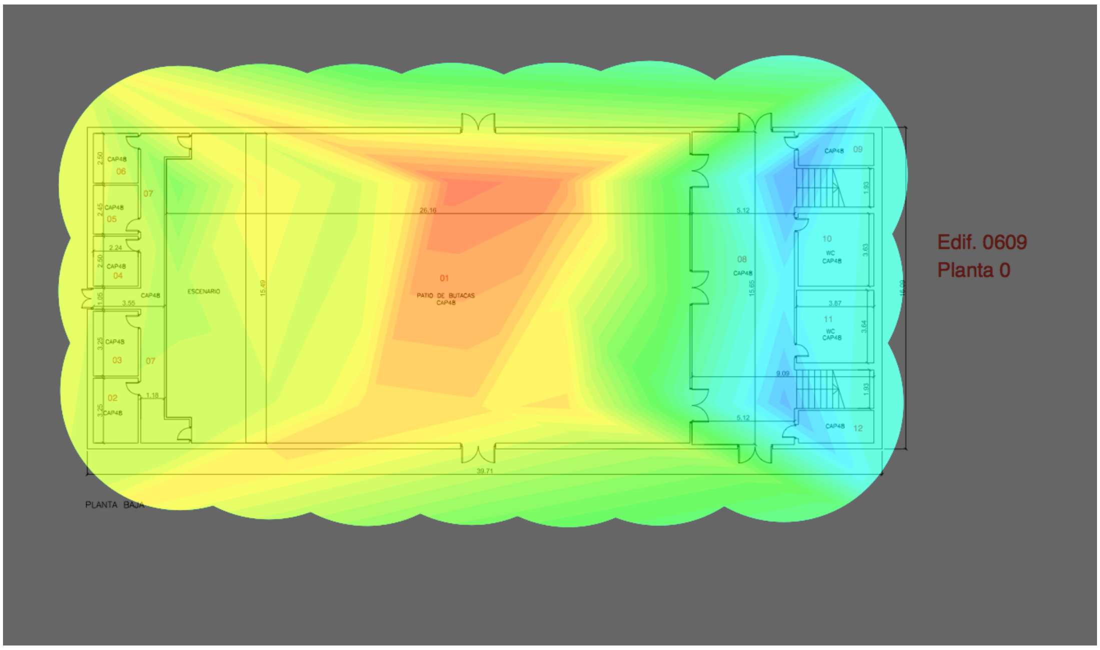
We see the location of the faculty on the following plan.



4.6.1. Building 0609 Floor 0

4.6.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

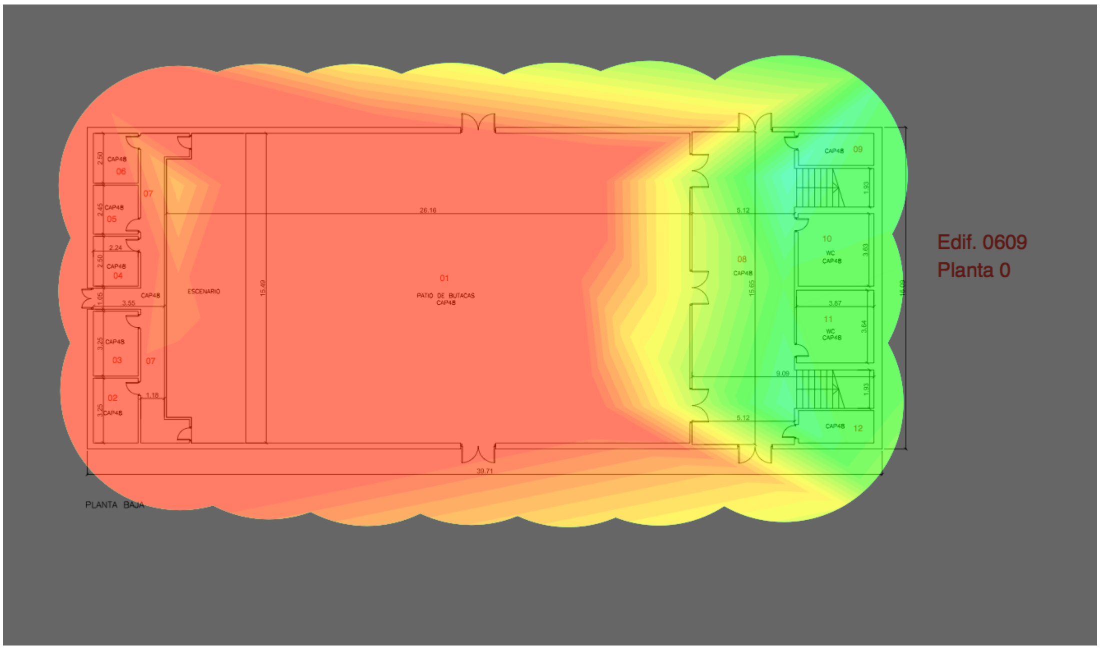


It can be seen that the areas are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.1.2. Signal Level



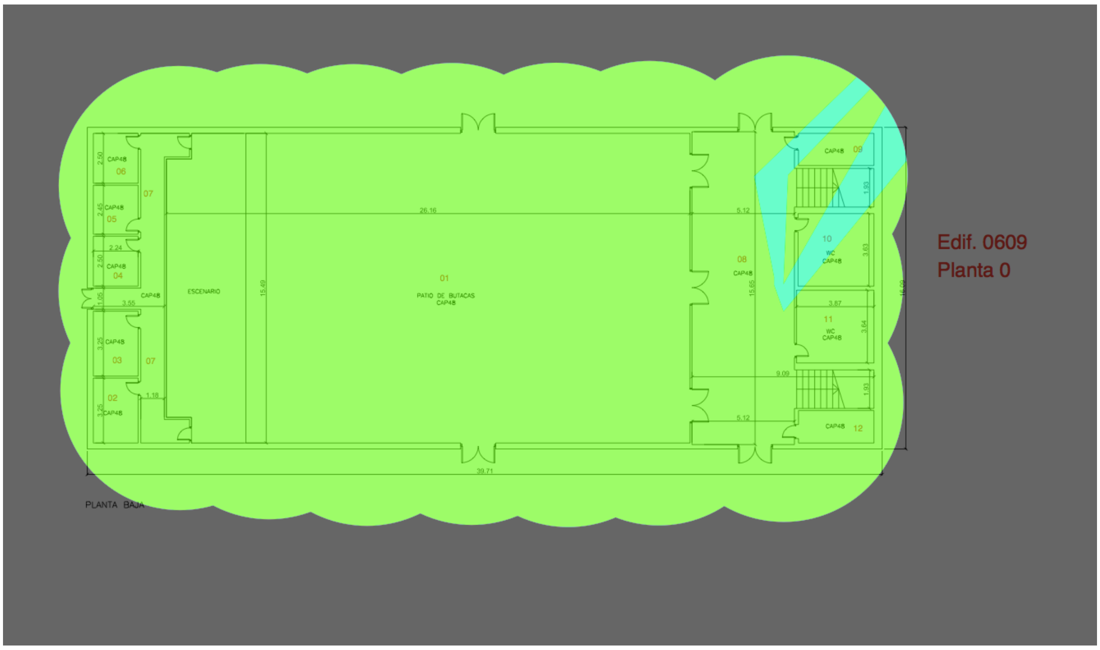
In this picture we can see again how the signal level in the areas are covered with a good intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

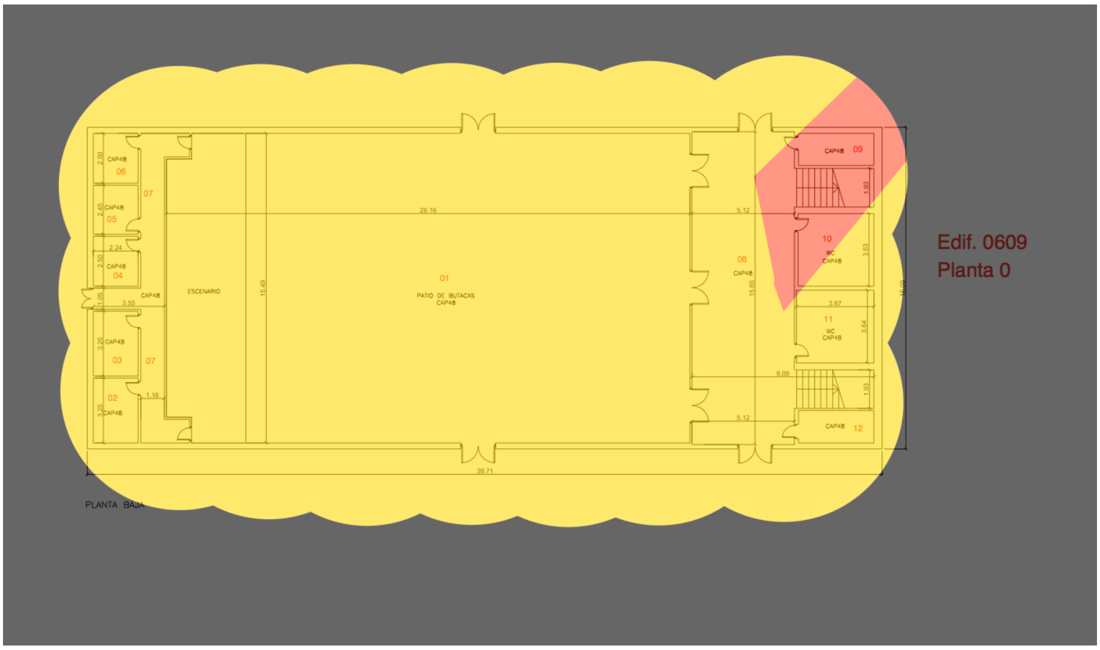
4.6.1.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.6.1.4. Coverage per Frequency Band



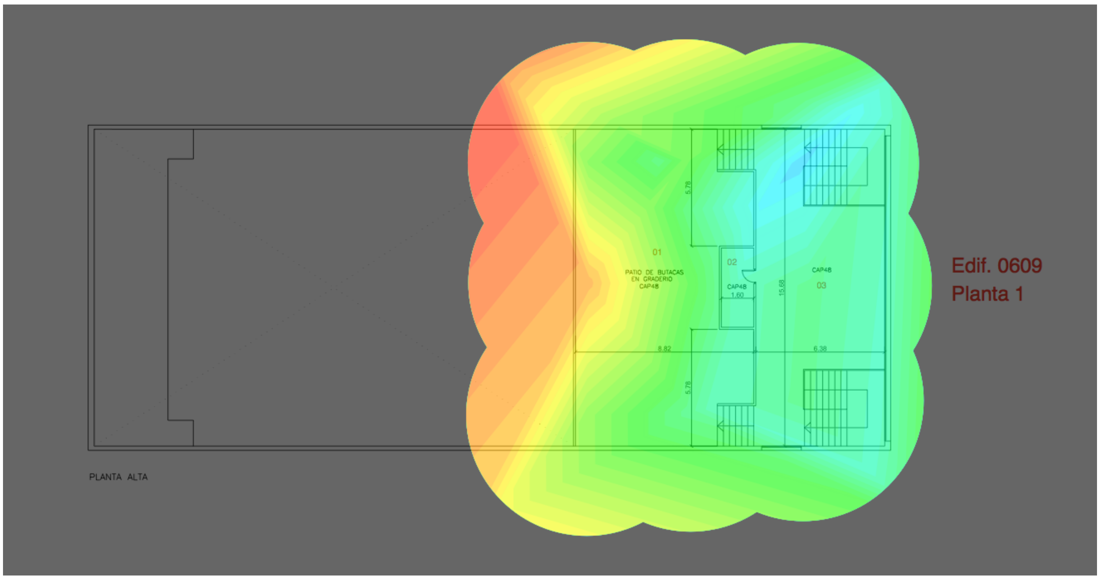
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.6.2. Building 0609 Floor 1

4.6.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

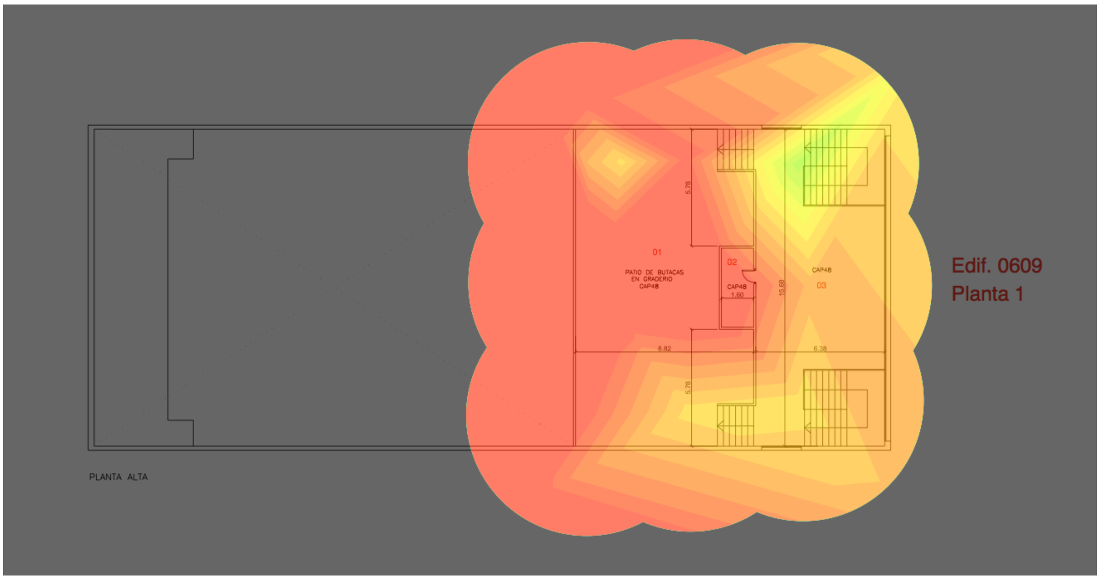


It can be seen that the areas are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.2.2. Signal Level



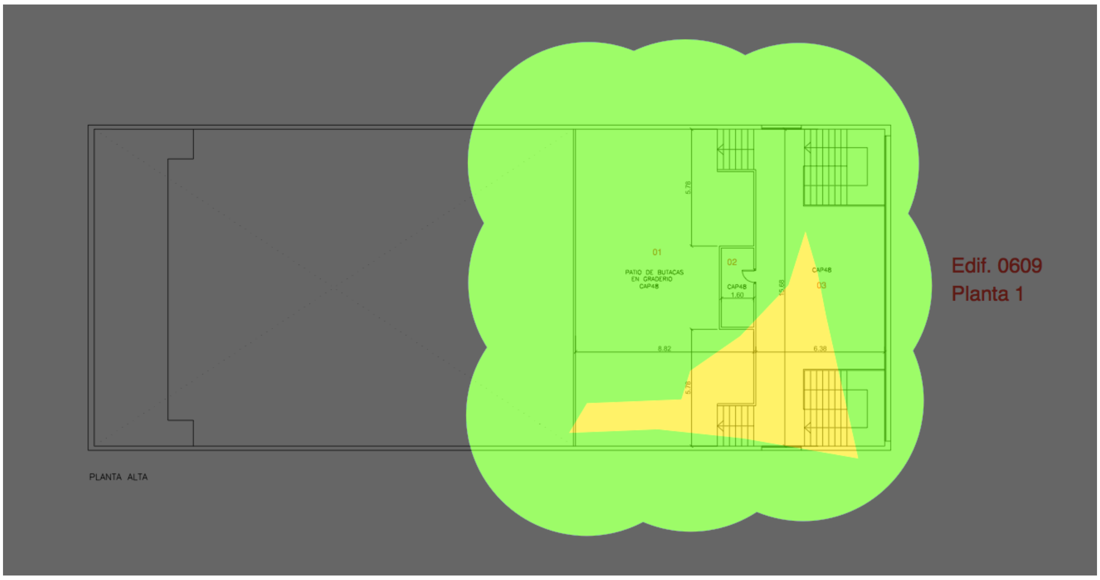
In this picture we can see again how the signal level in the areas are covered with a good intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.6.2.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

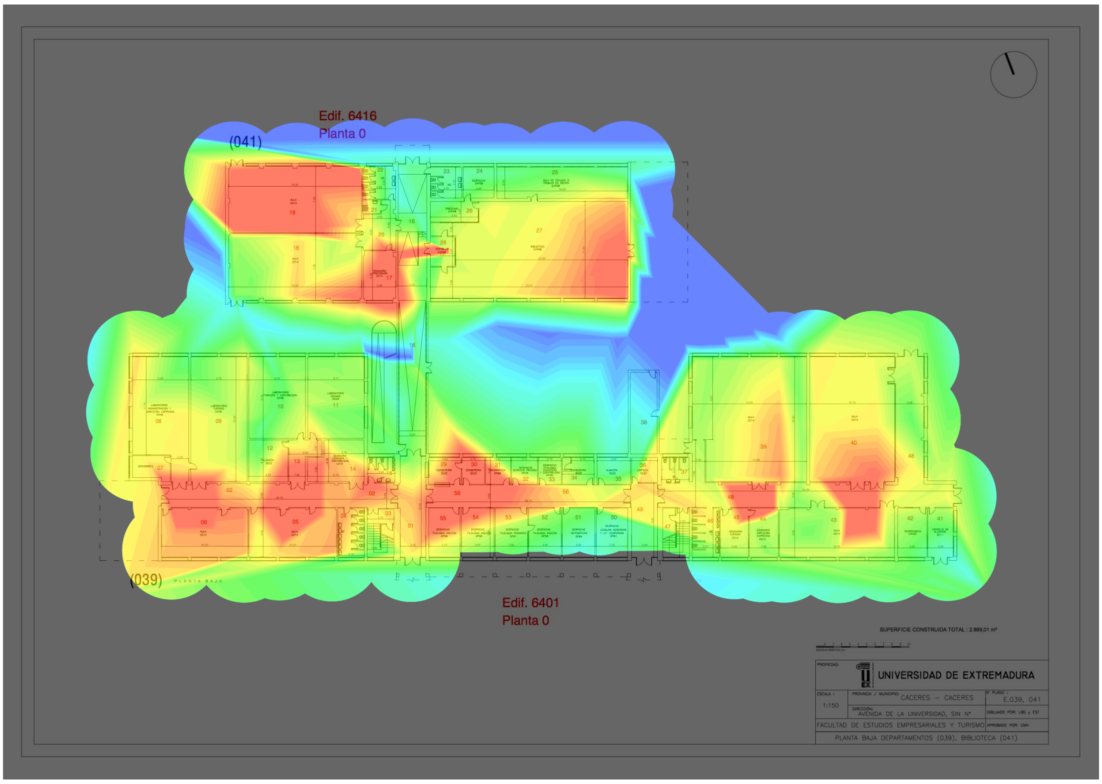
4.6.2.4. Coverage per Frequency Band

In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.6.11. Building 6401-6416 Floor 0

4.6.11.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

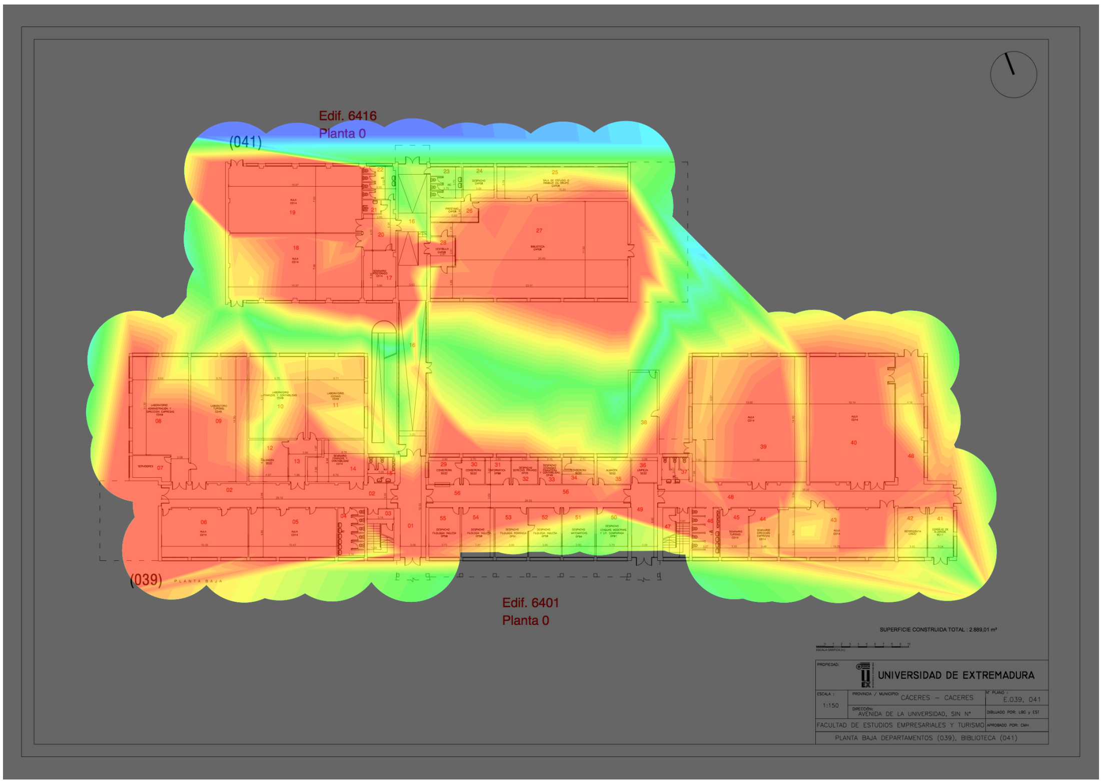


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.11.2. Signal Level



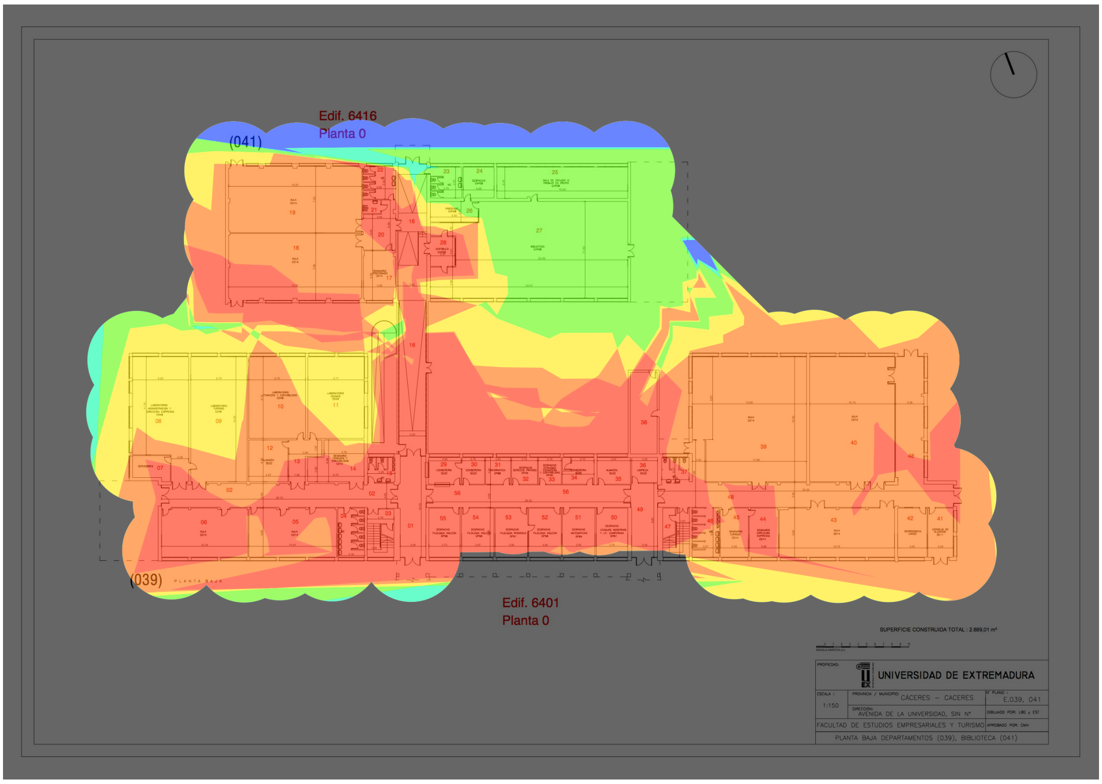
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.6.11.3. Number of Access Points

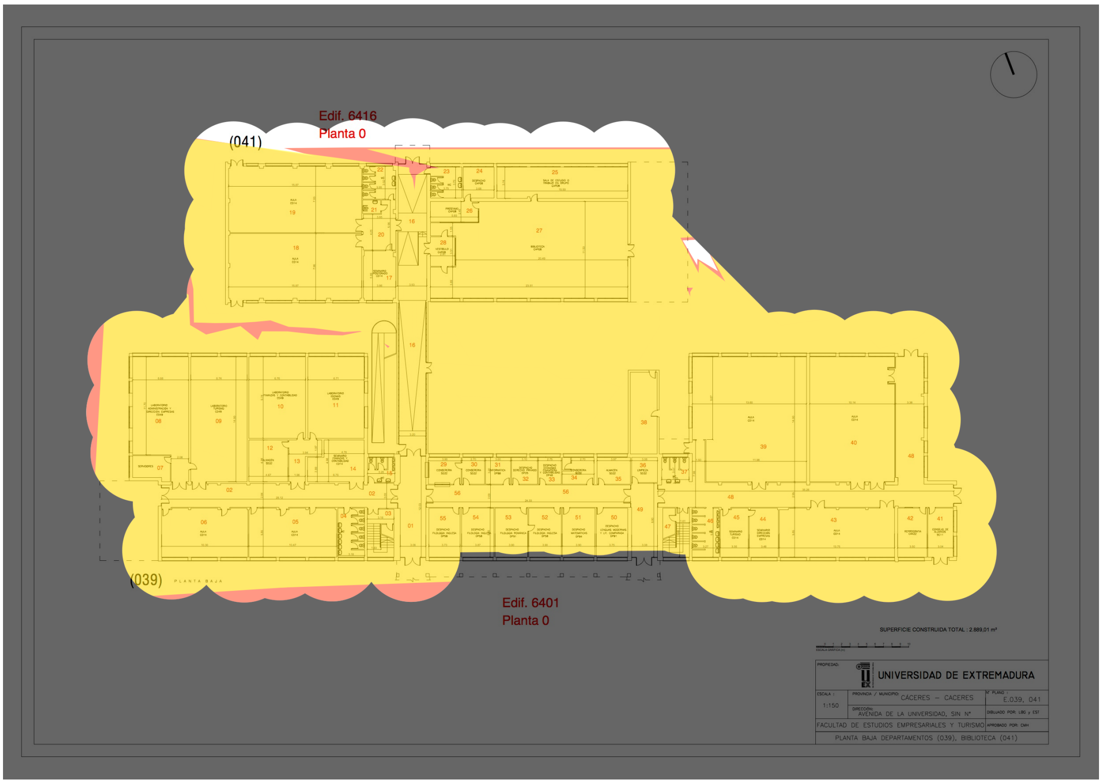


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.6.11.4. Coverage per Frequency Band



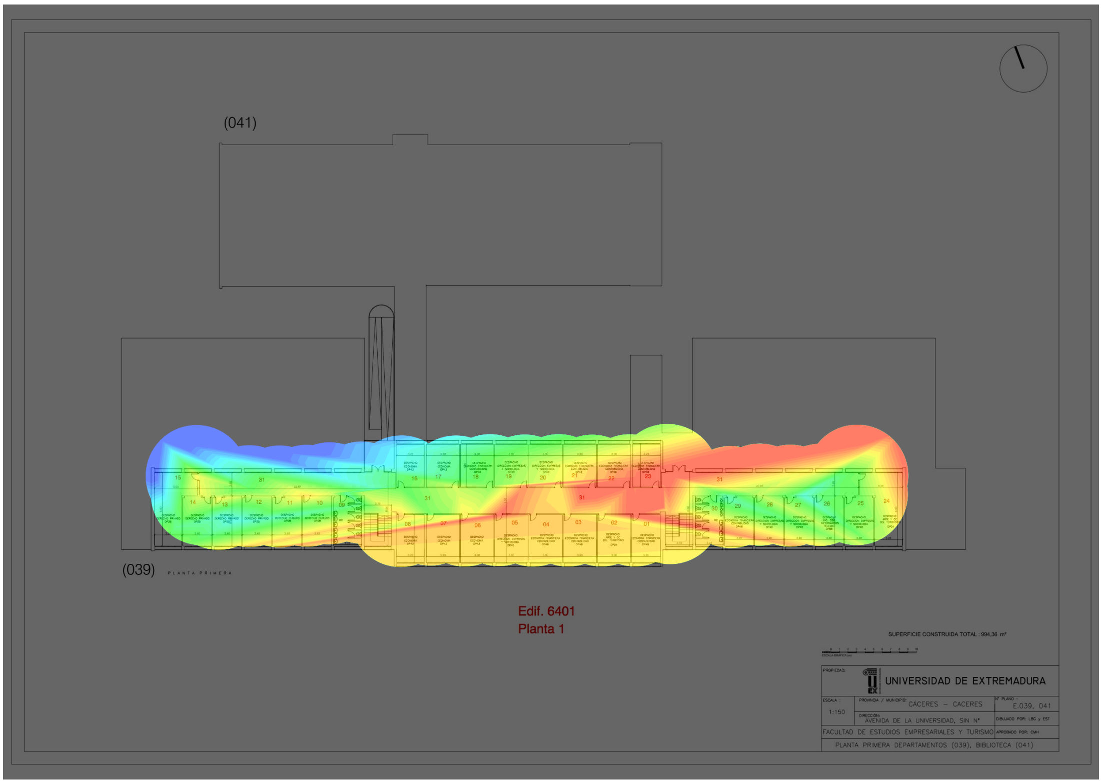
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.6.12. Building 6401-6416 Floor 1

4.6.12.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

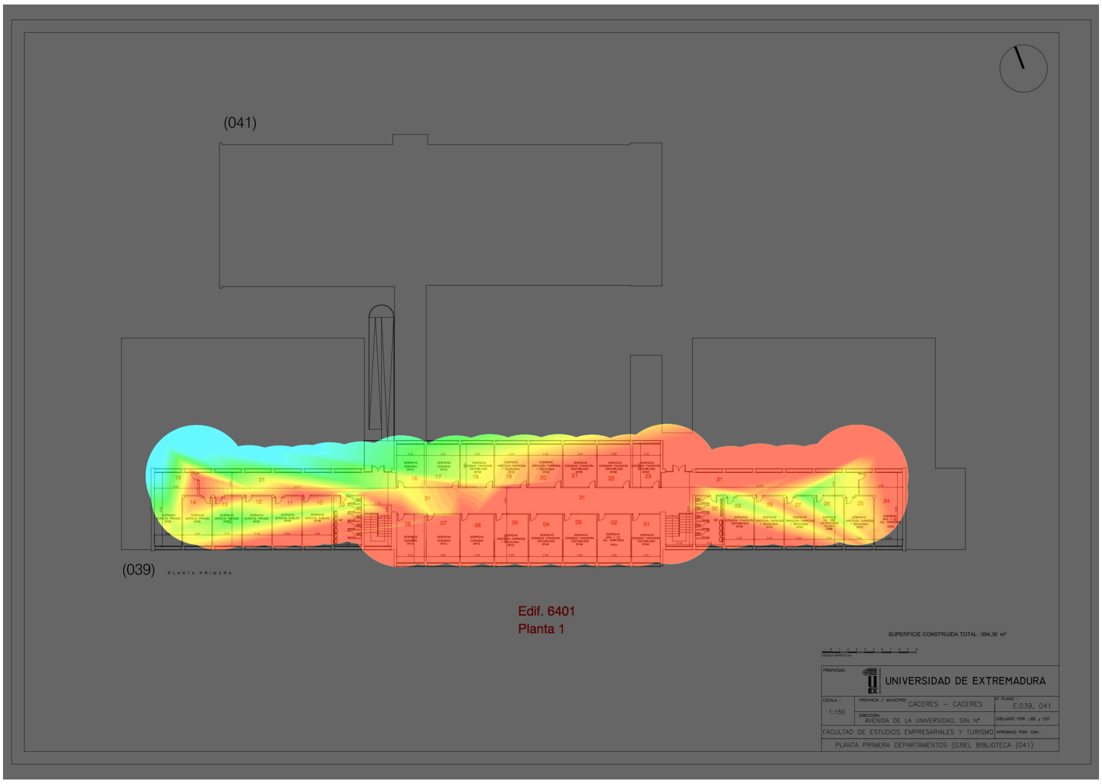


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.12.2. Signal Level



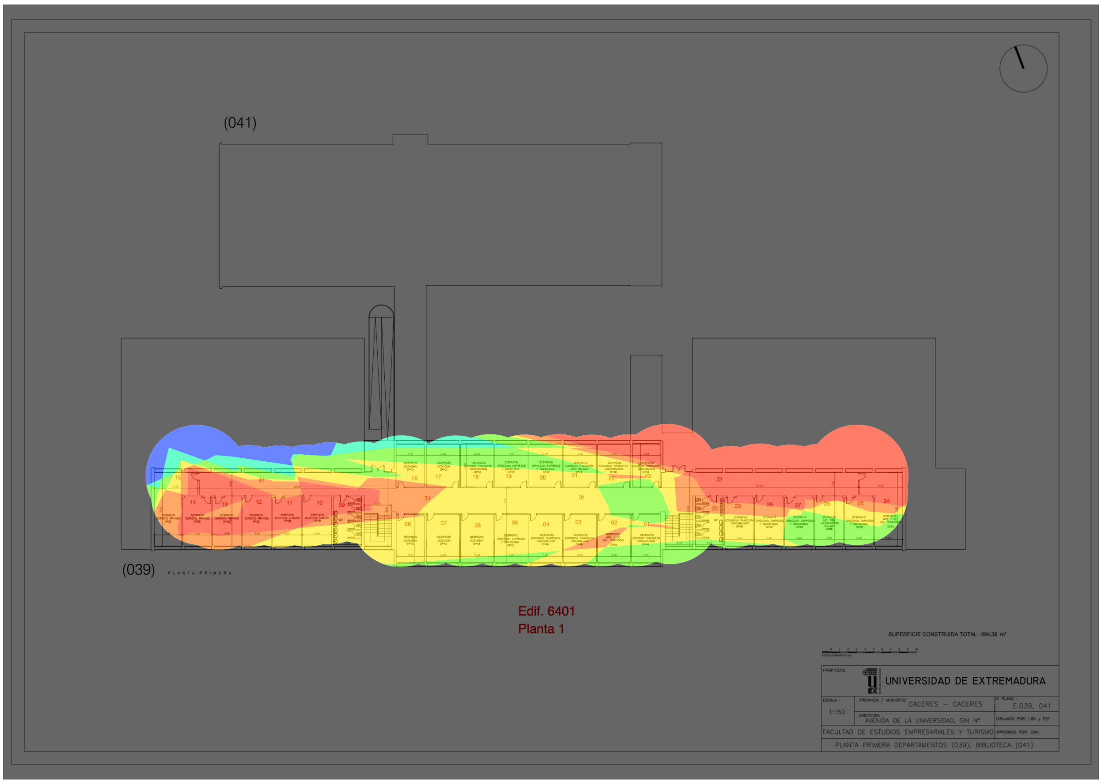
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.6.12.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.6.12.4. Coverage per Frequency Band

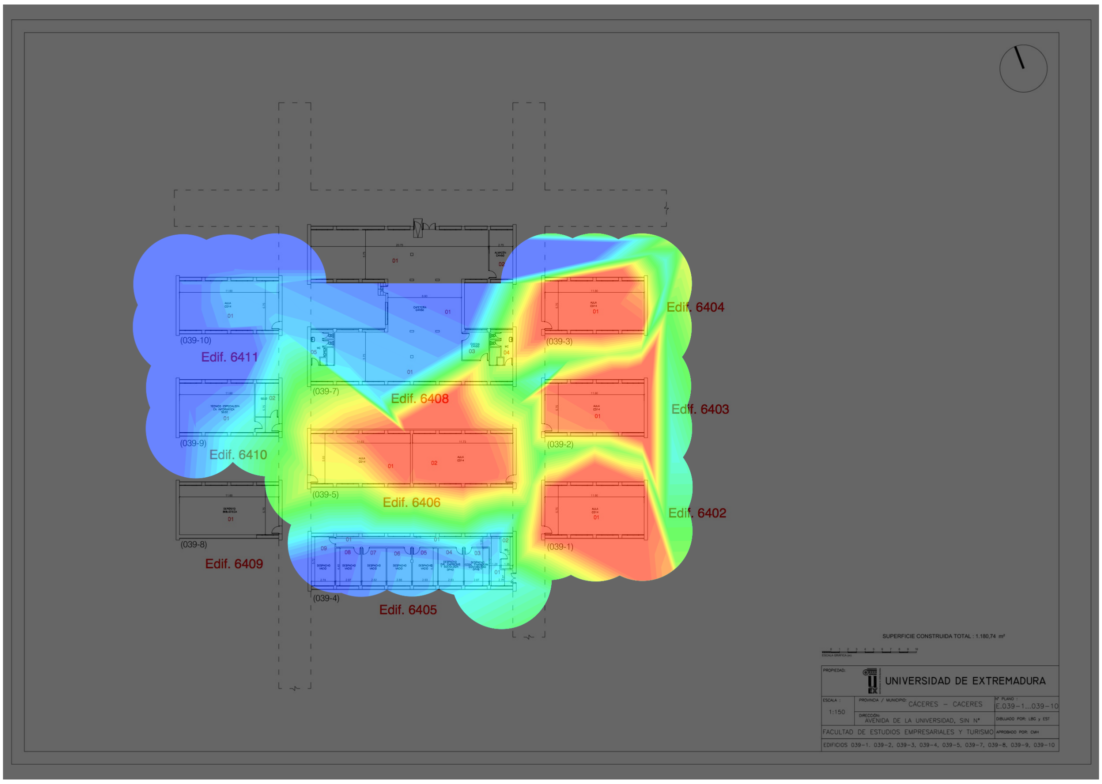
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.6.21. Building 6402-6411 Floor 0

4.6.21.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

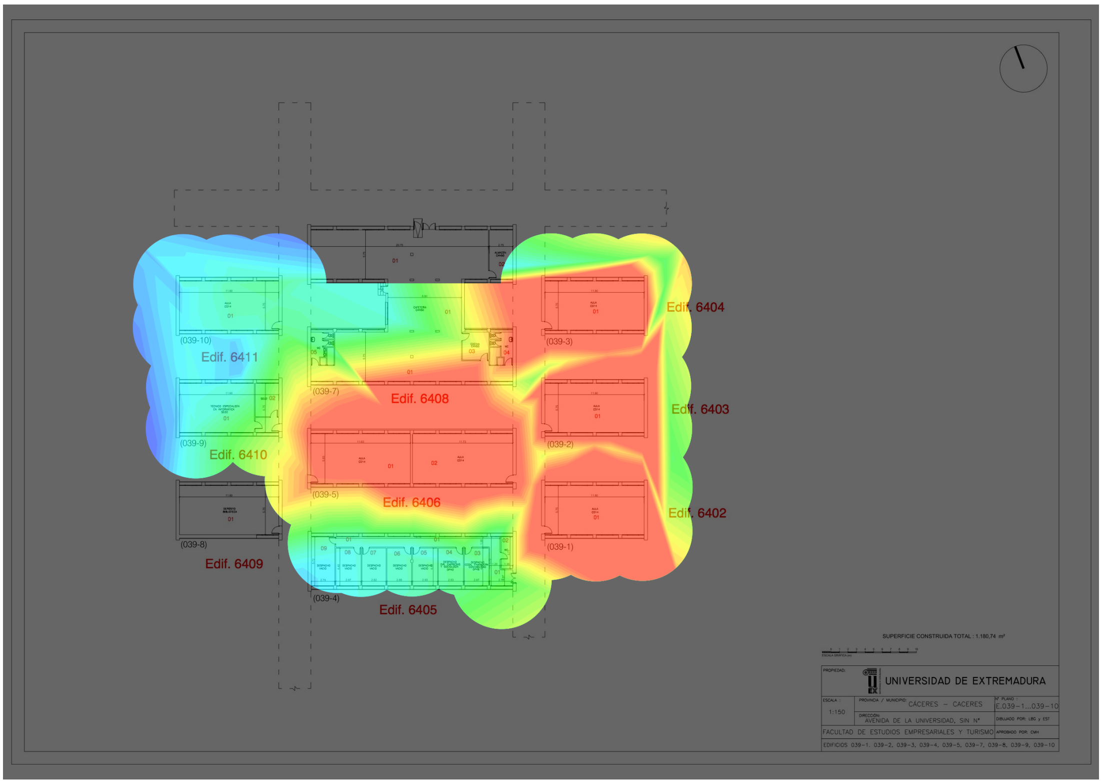


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.21.2. Signal Level



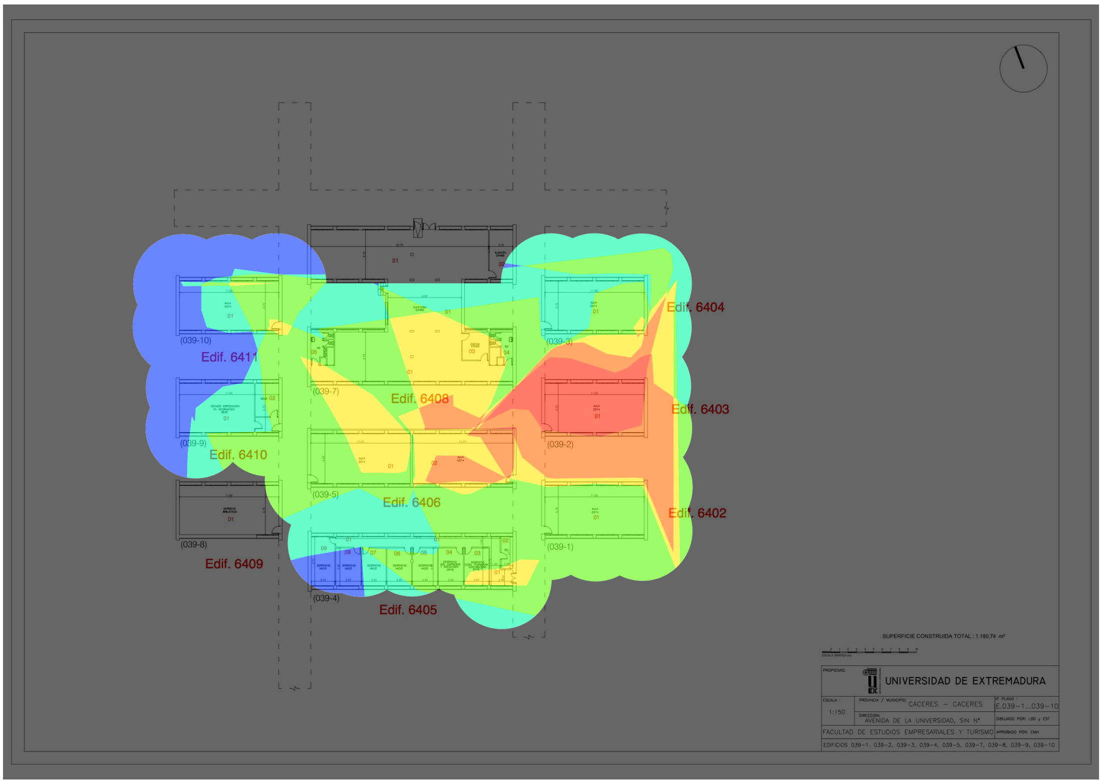
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.6.21.3. Number of Access Points

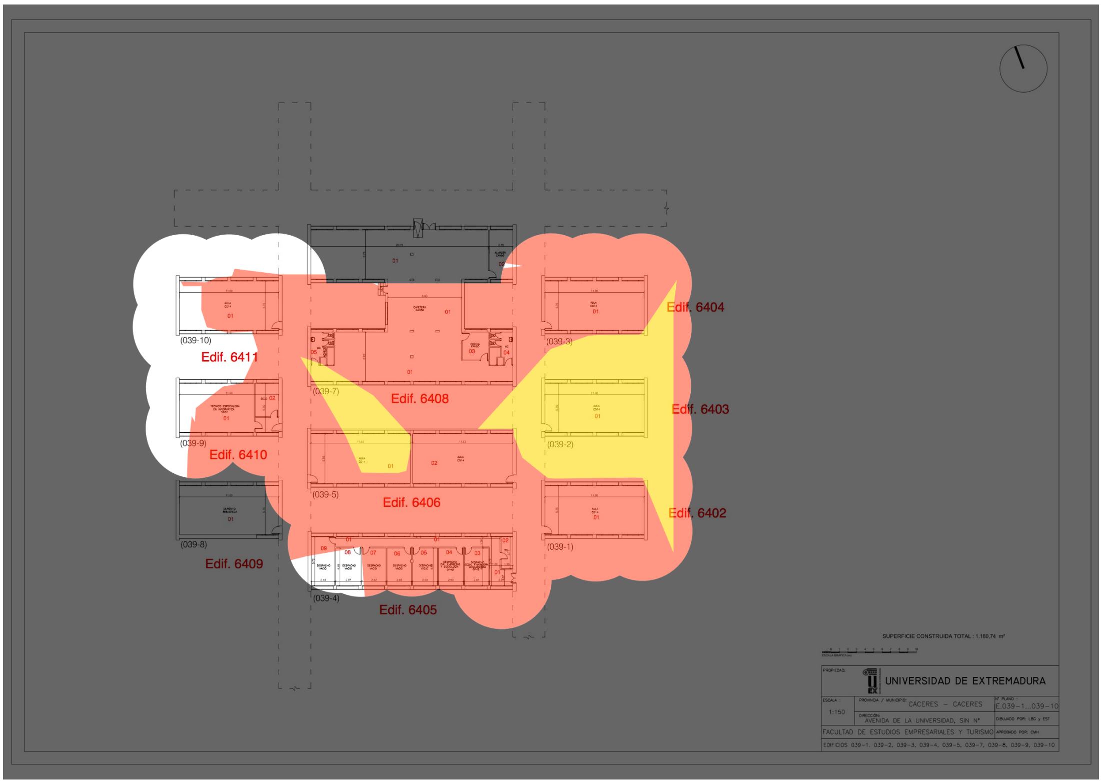


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.6.21.4. Coverage per Frequency Band



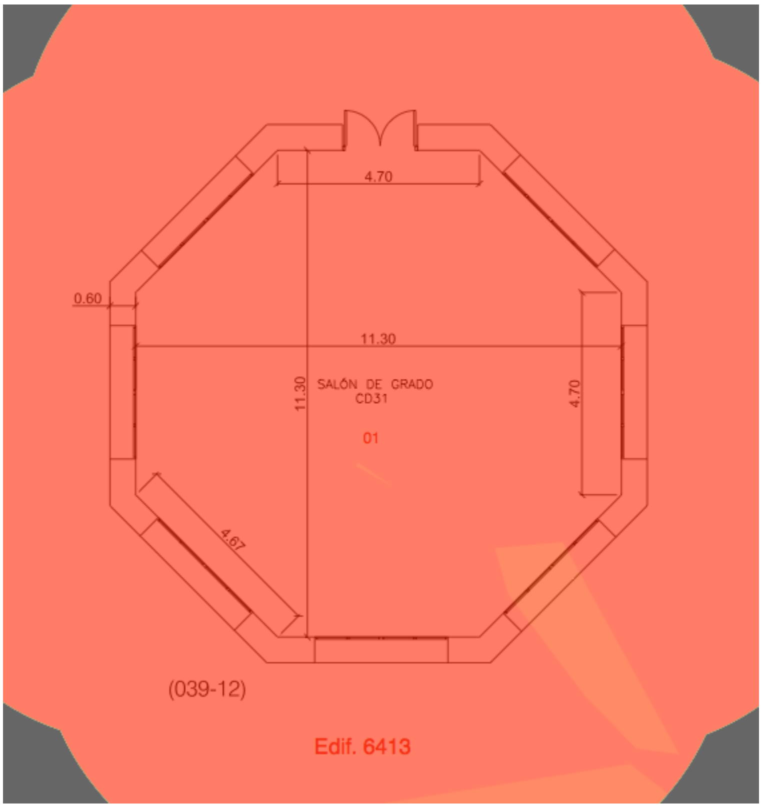
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.6.31. Building 6413 Floor 0

4.6.31.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

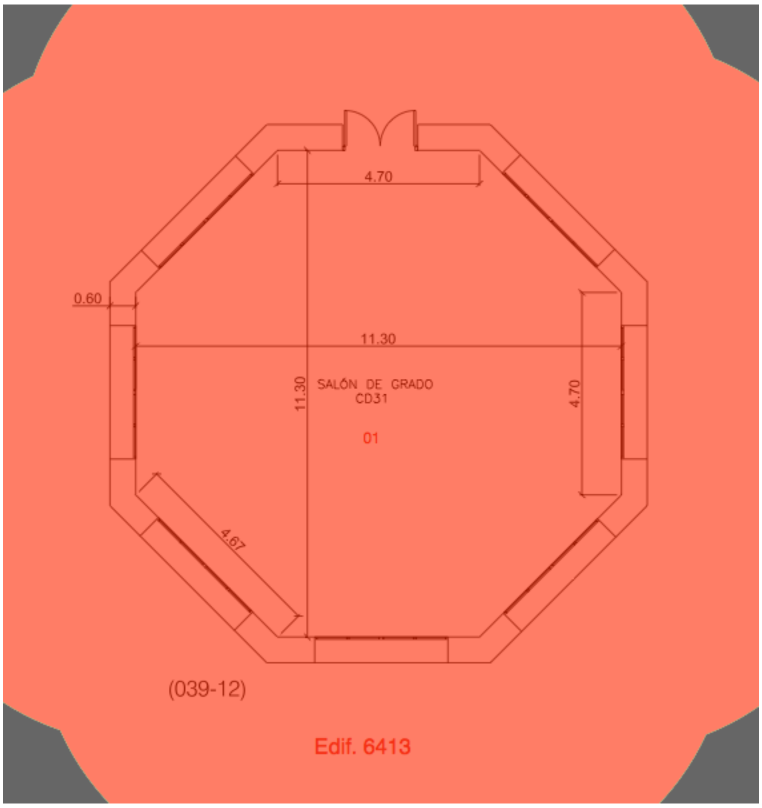


It can be seen that the areas are covered with a good quality signal.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.31.2. Signal Level



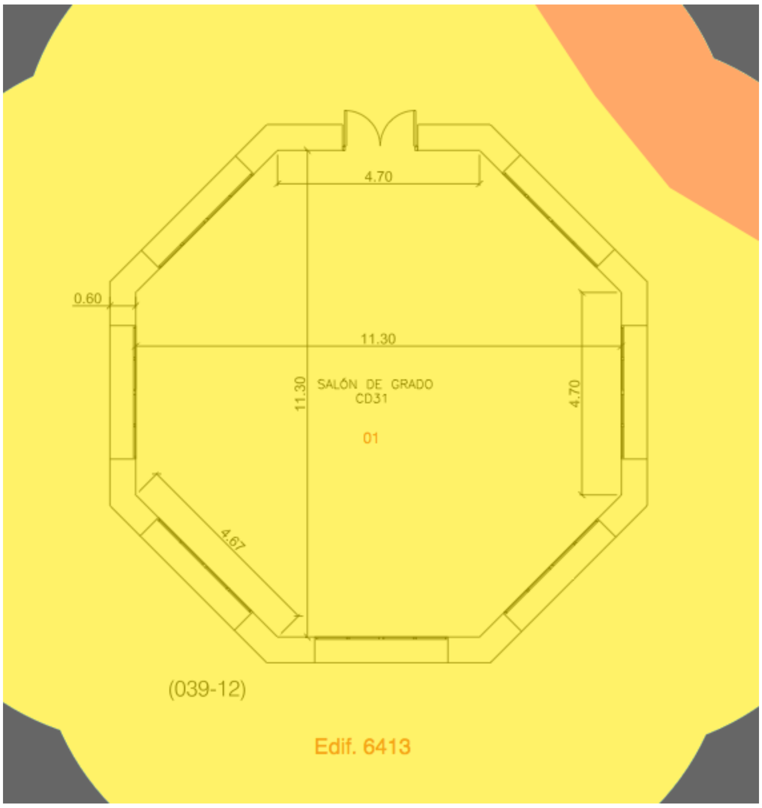
In this picture we can see again how the signal level in the areas are covered with a good intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

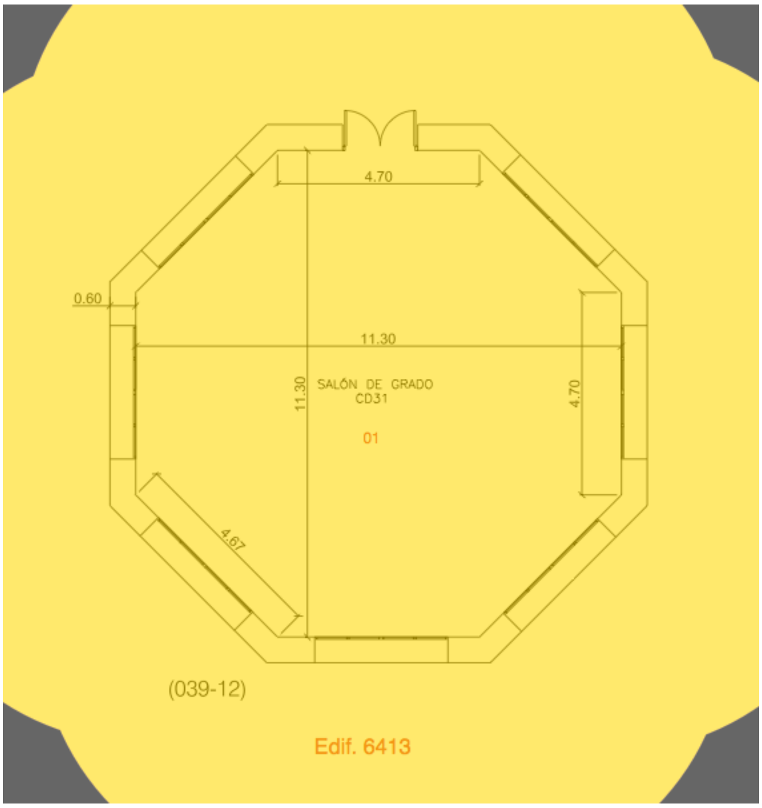
4.6.31.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.6.31.4. Coverage per Frequency Band

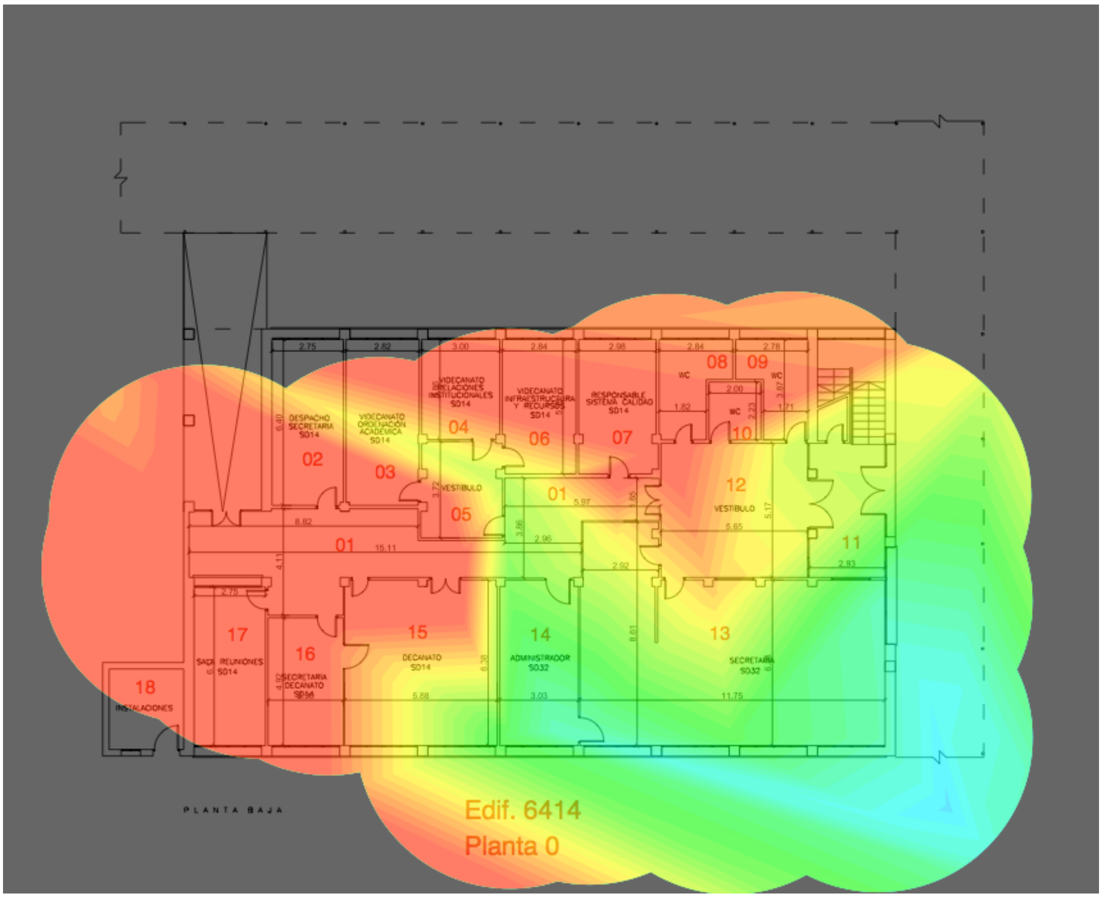


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.6.41. Building 6414 Floor 0

4.6.41.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

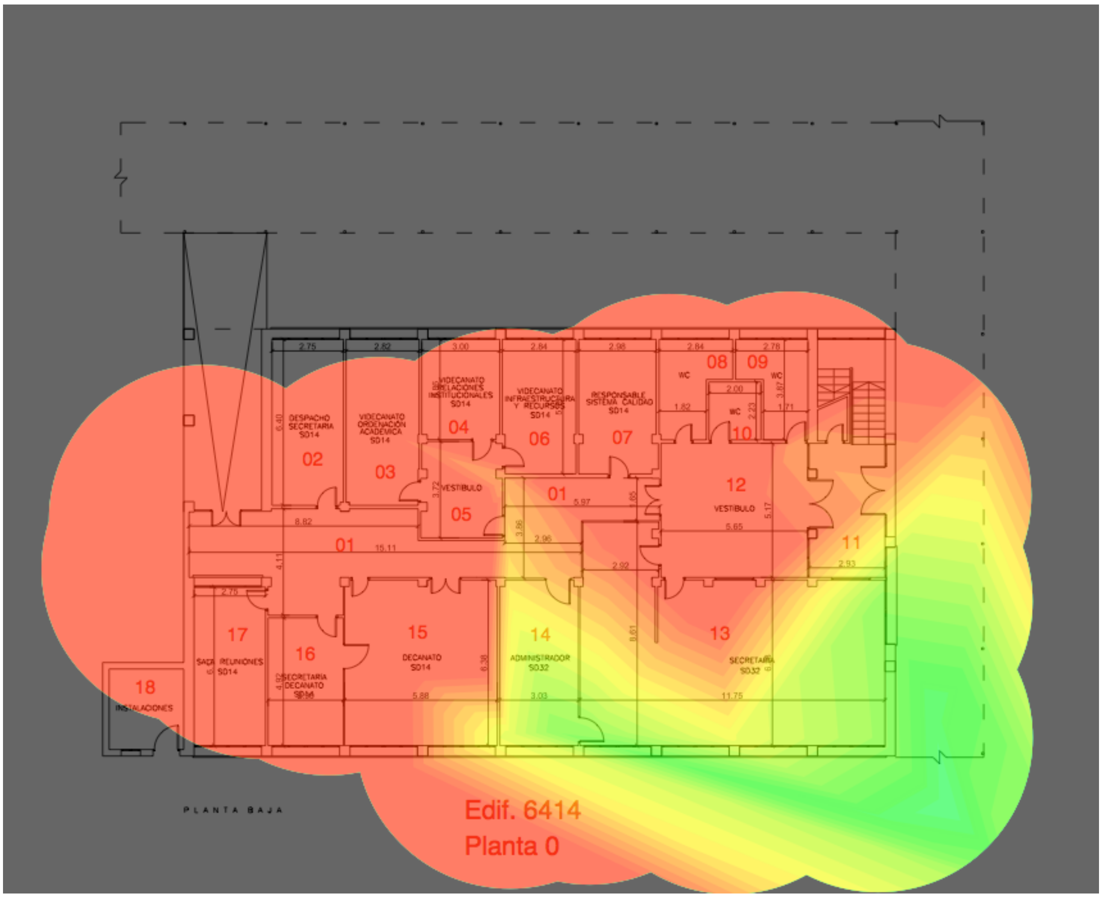


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.41.2. Signal Level



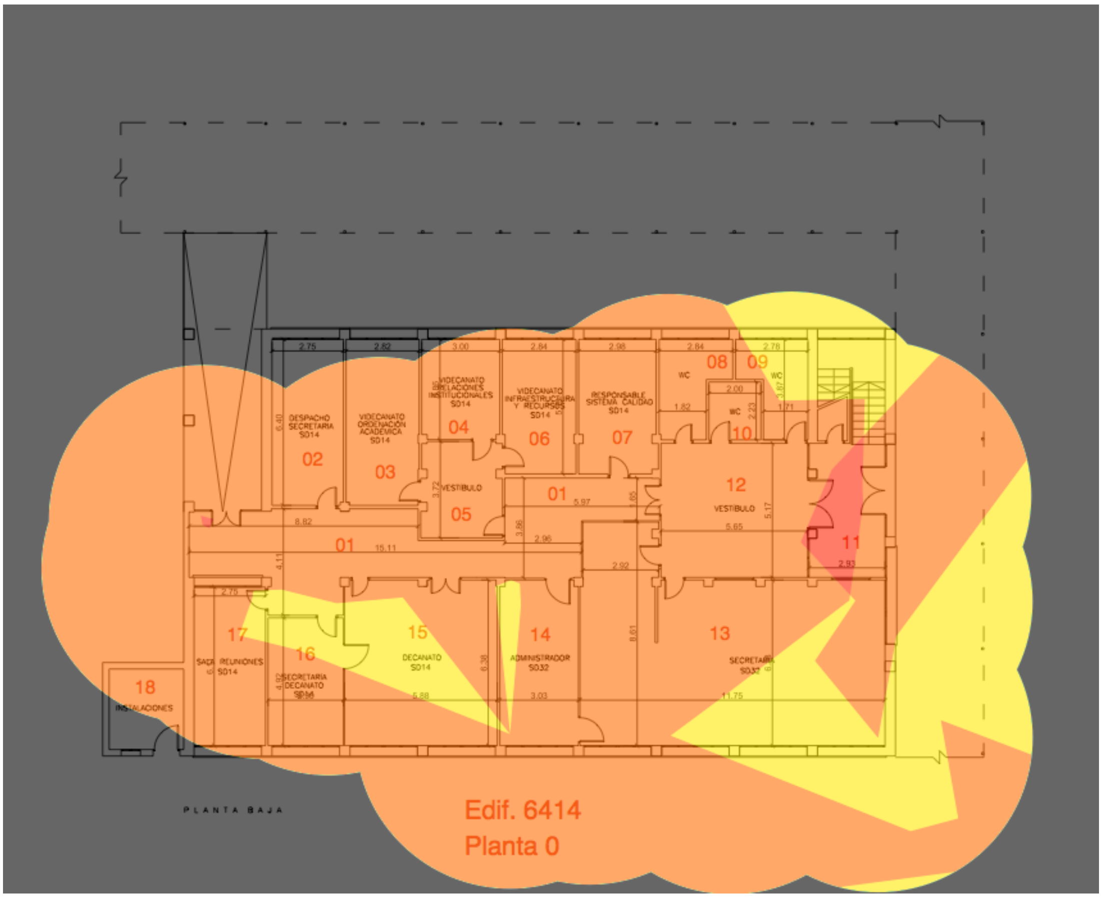
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.6.41.3. Number of Access Points

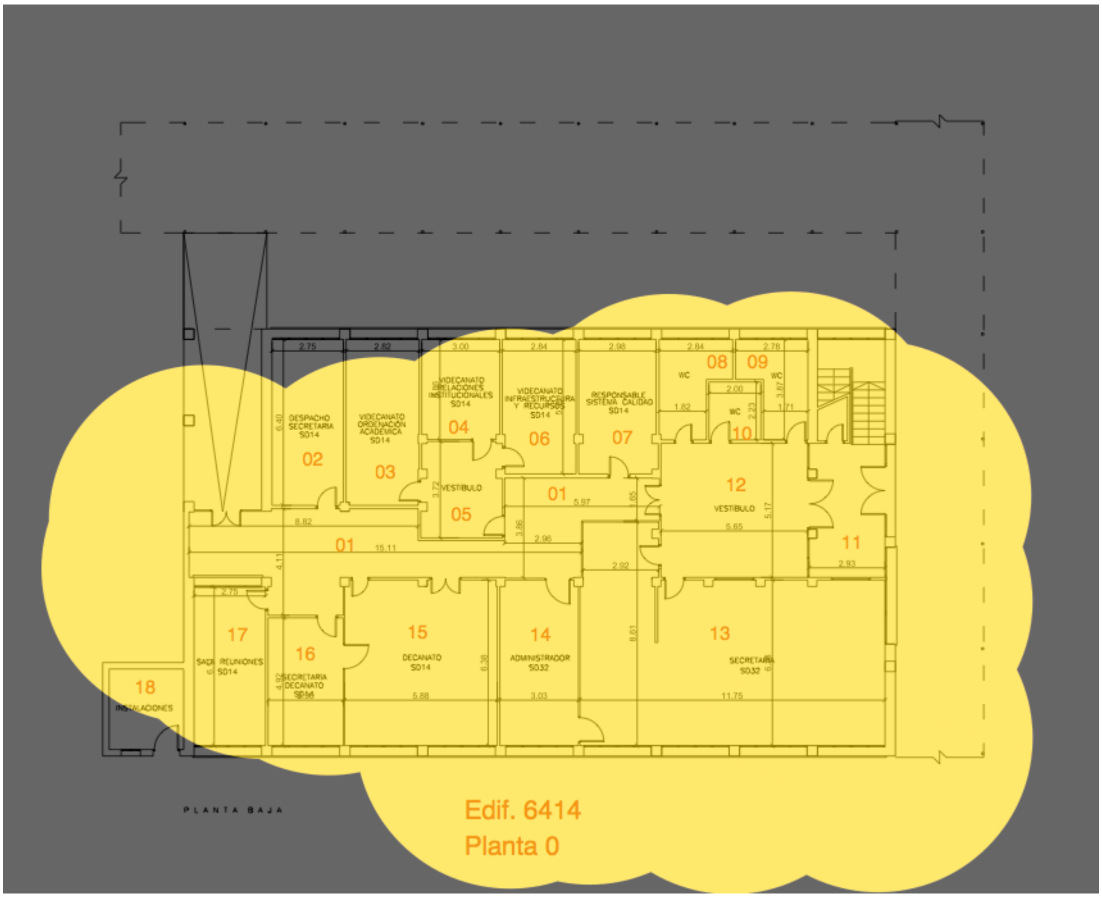


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.6.41.4. Coverage per Frequency Band

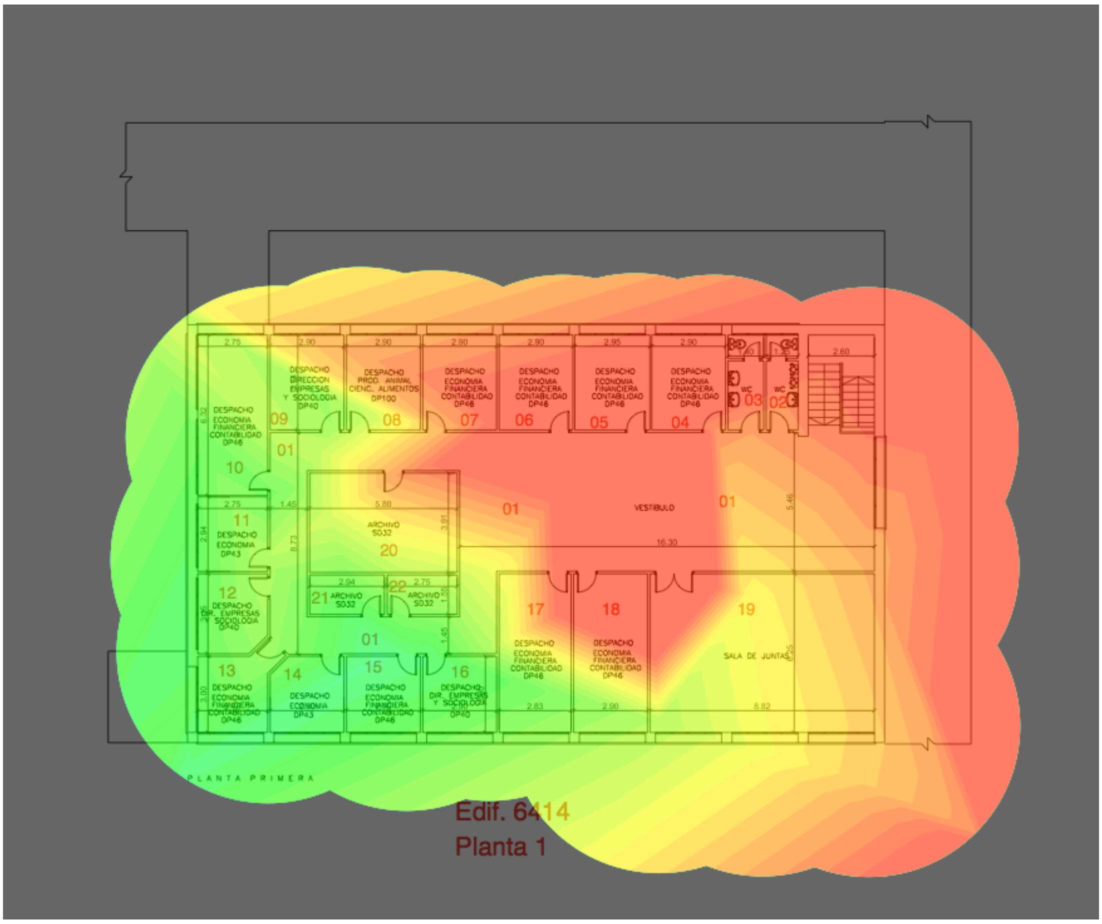


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.6.42. Building 6414 Floor 1

4.6.42.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

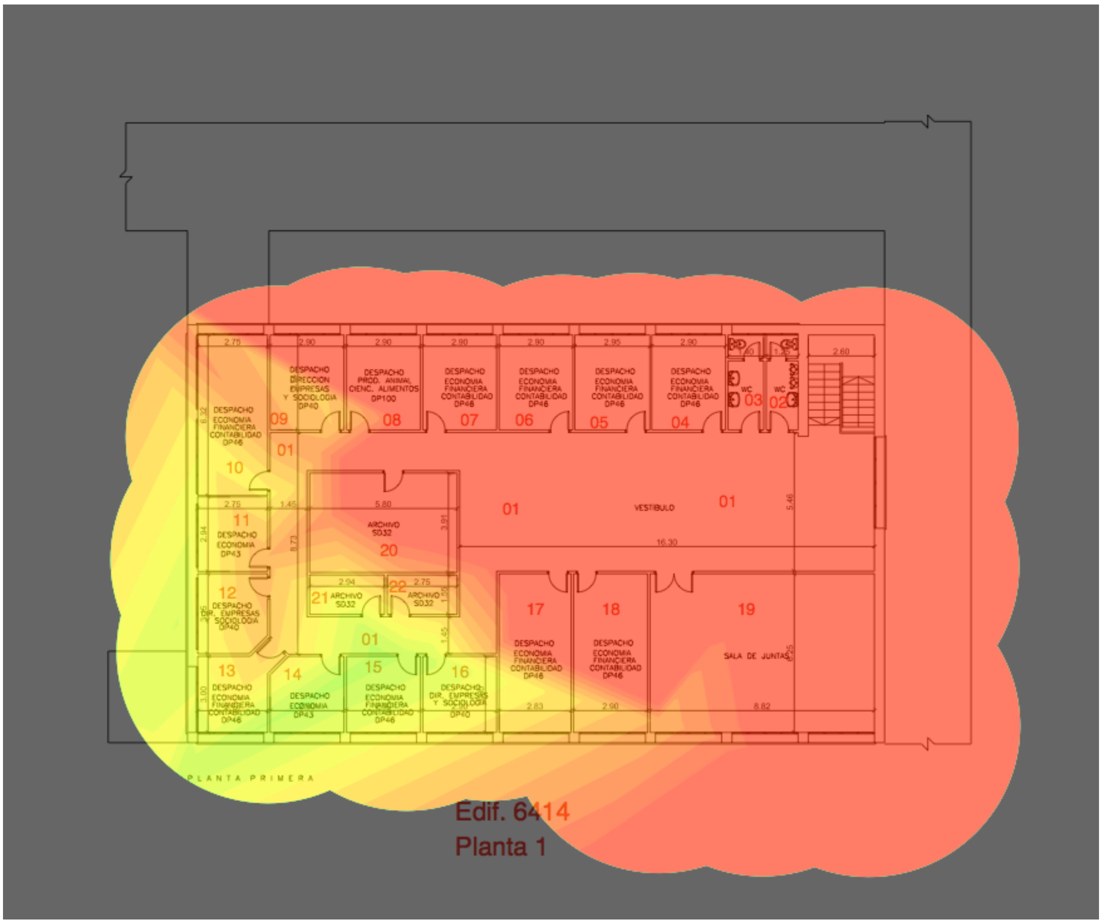


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.42.2. Signal Level



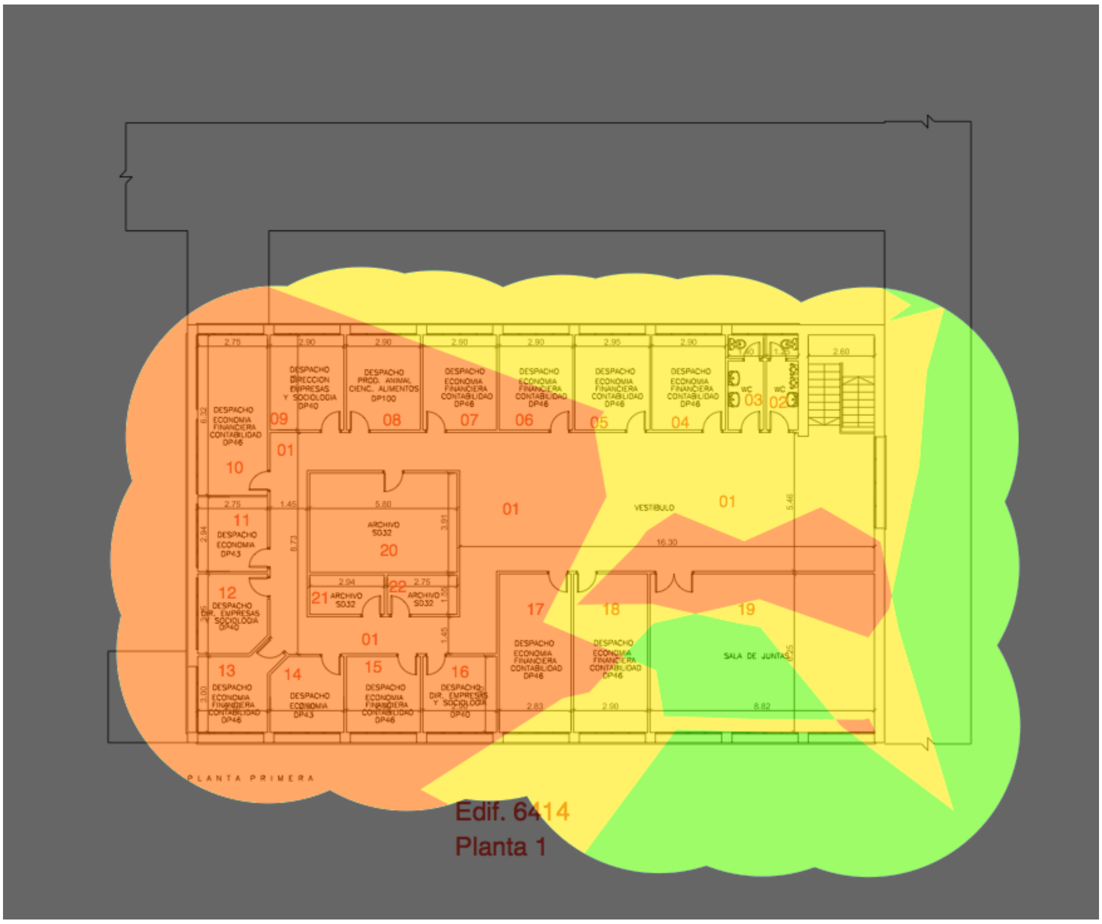
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.6.42.3. Number of Access Points

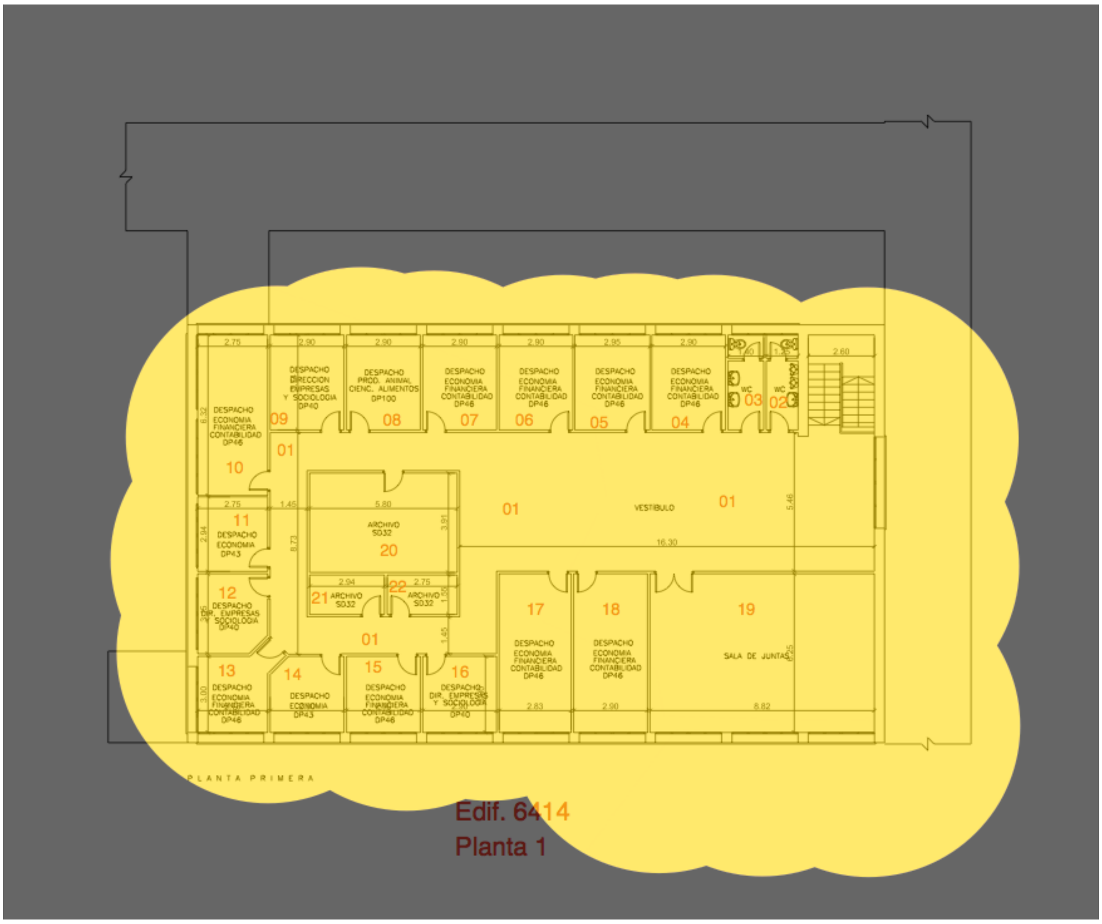


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.6.42.4. Coverage per Frequency Band

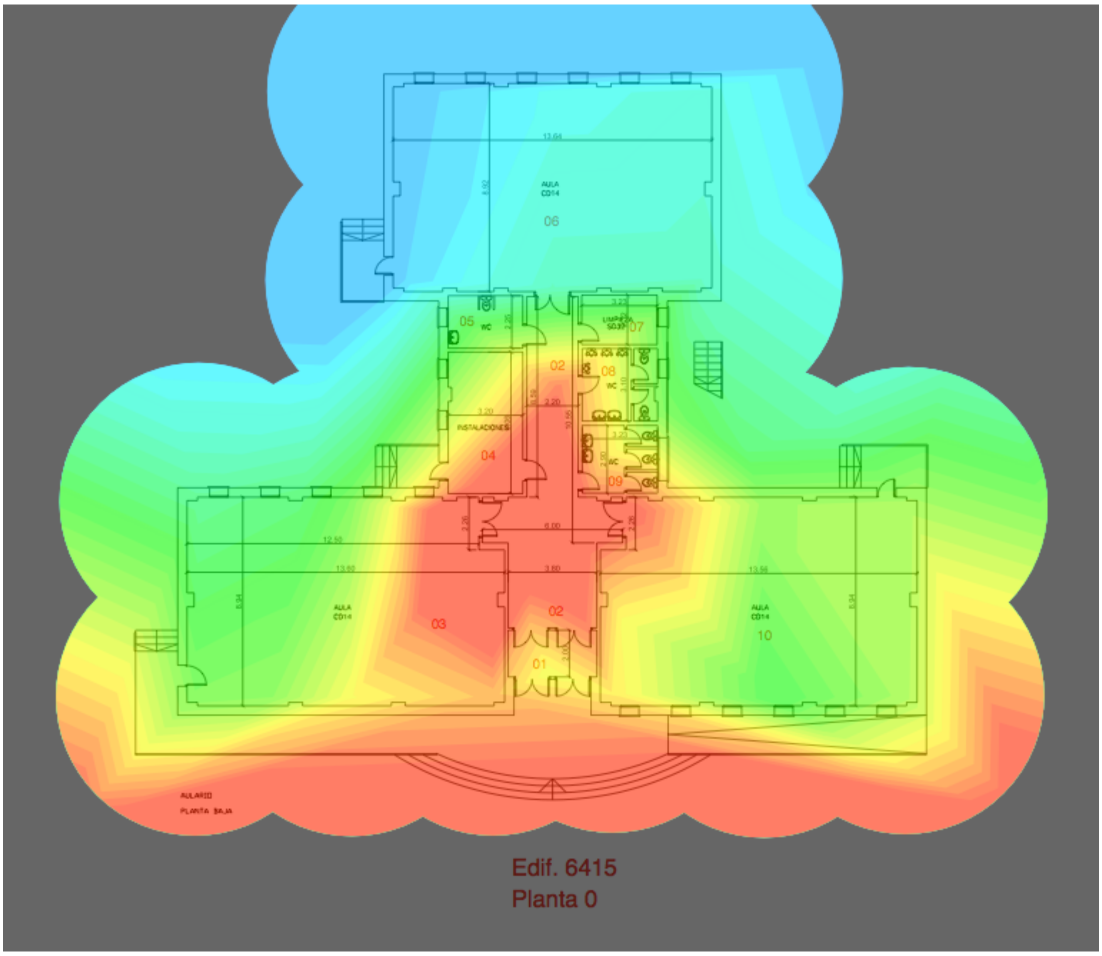


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.6.51. Building 6415 Floor 0

4.6.51.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

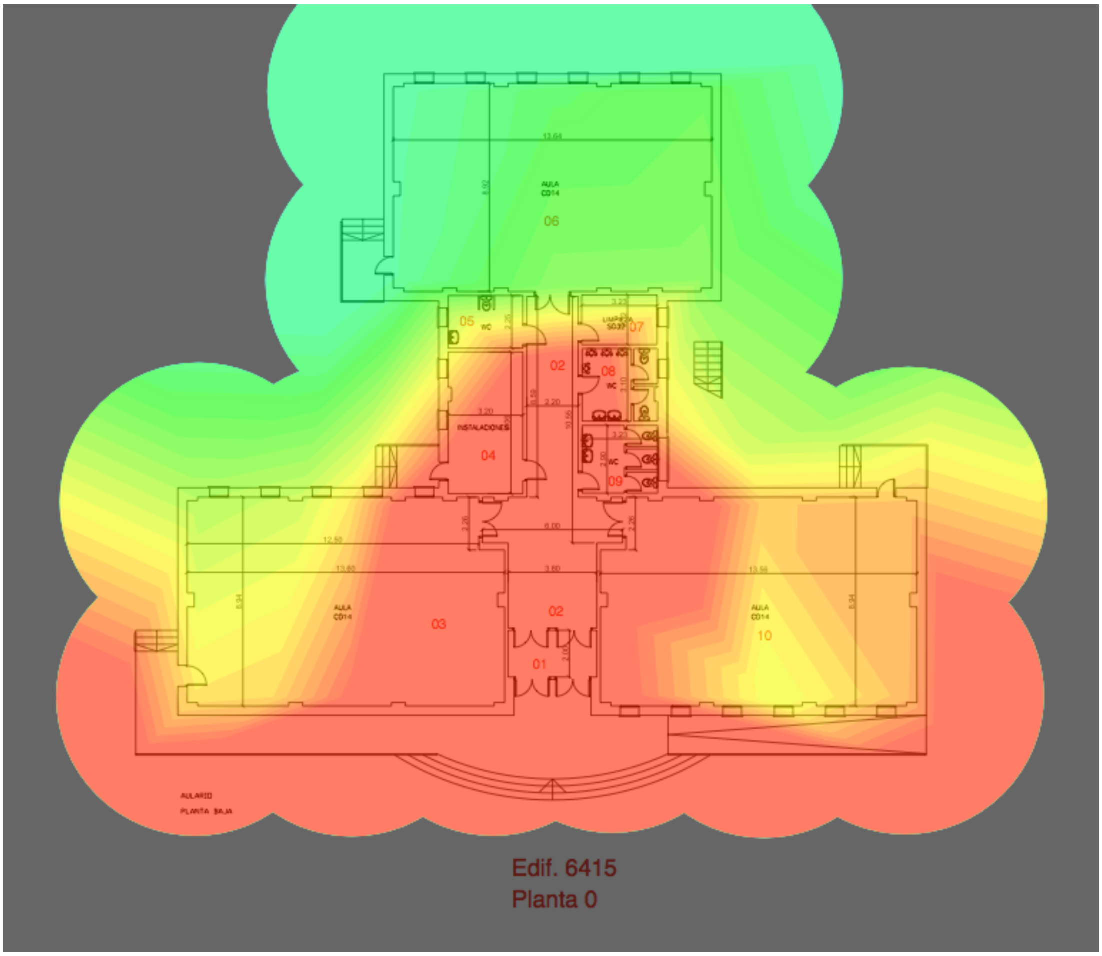


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.51.2. Signal Level



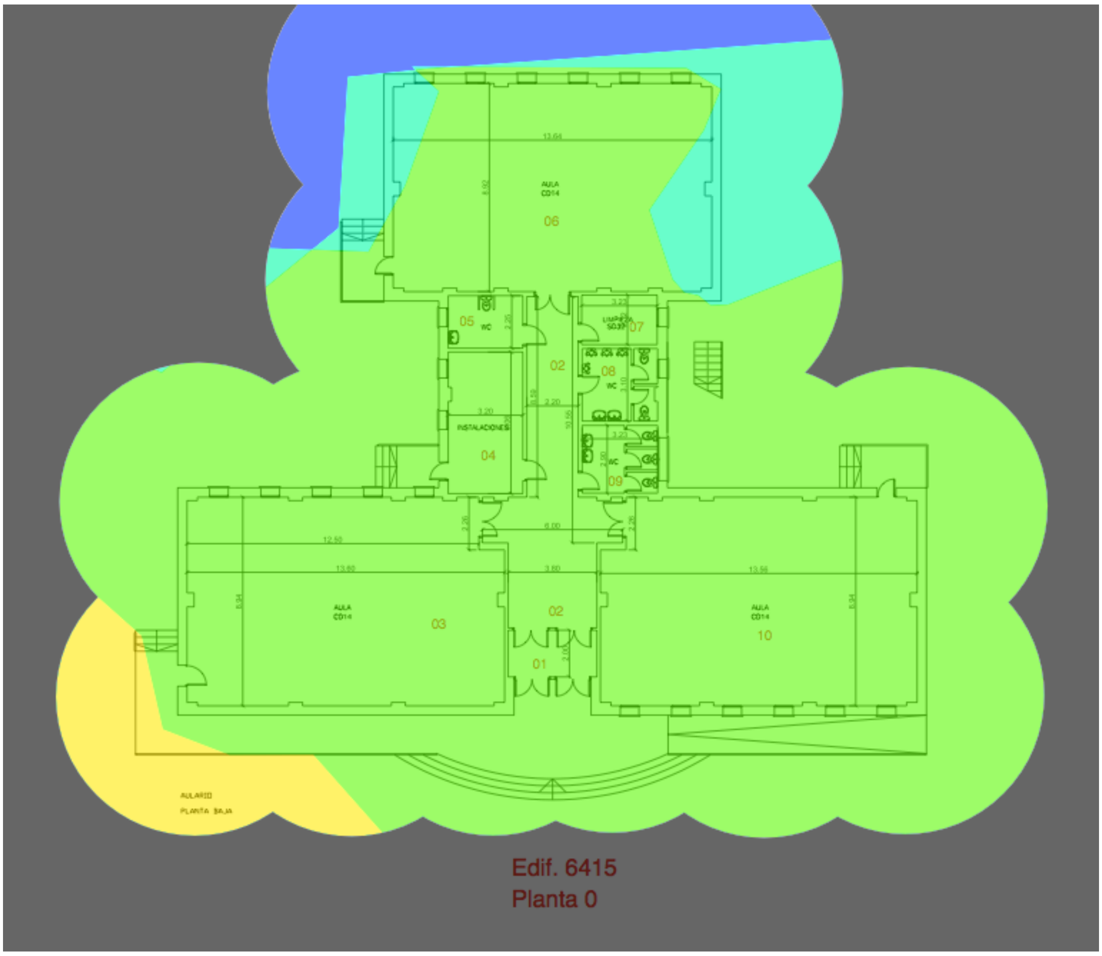
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.6.51.3. Number of Access Points

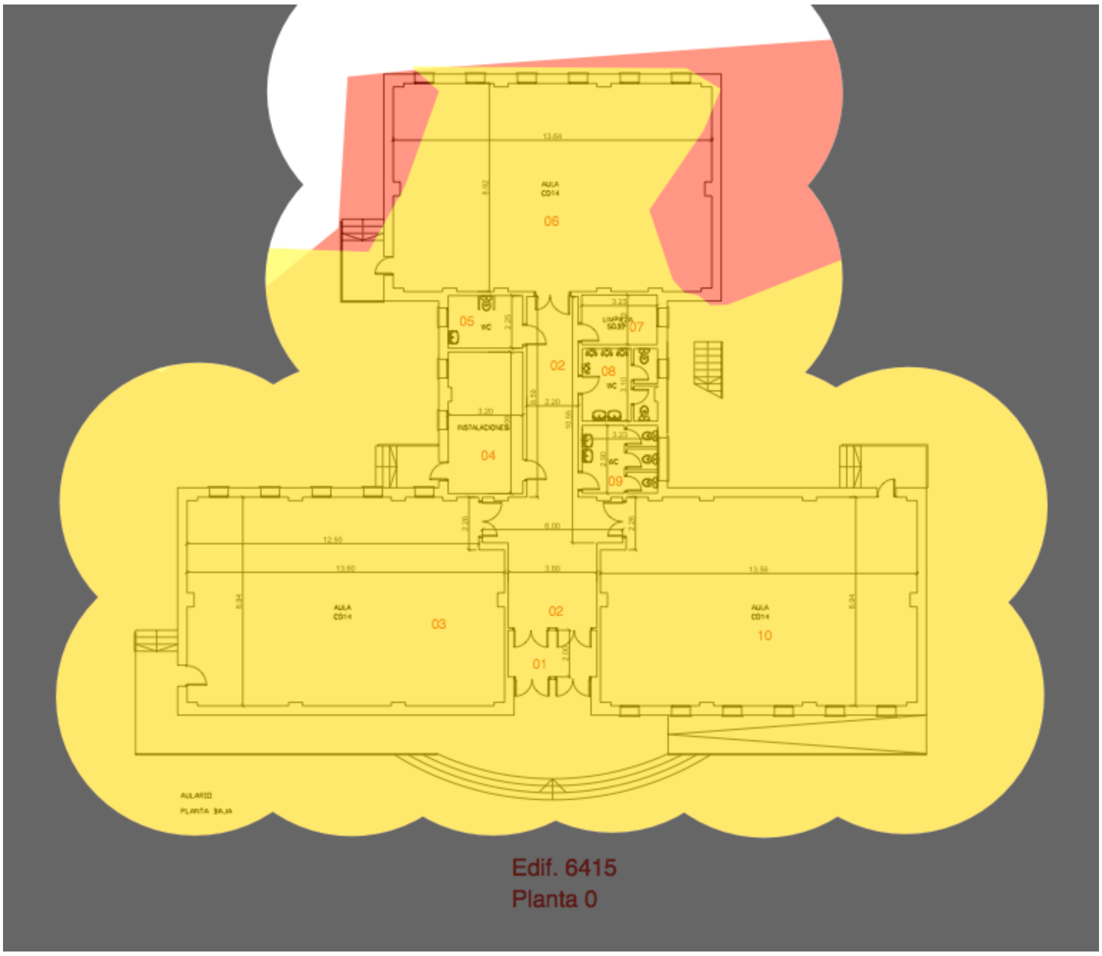


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.6.51.4. Coverage per Frequency Band



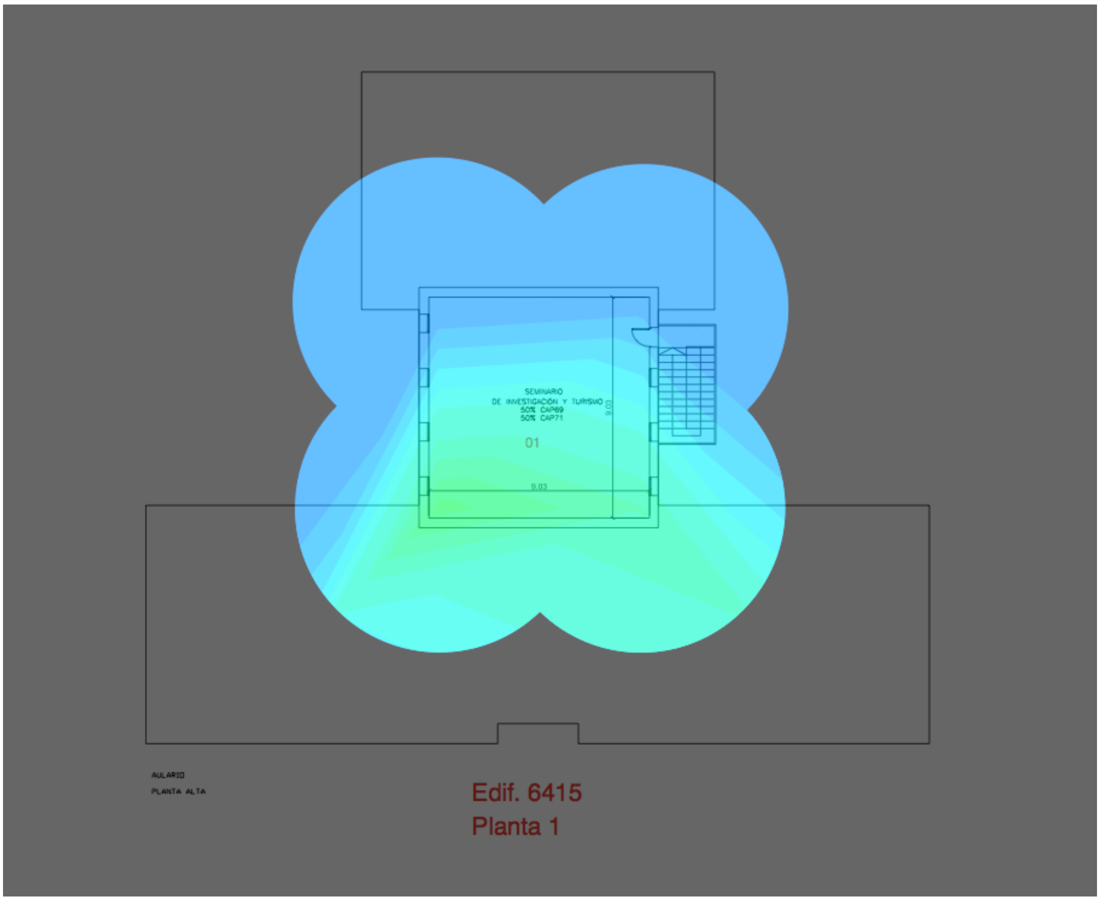
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.6.52. Building 6415 Floor 1

4.6.52.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

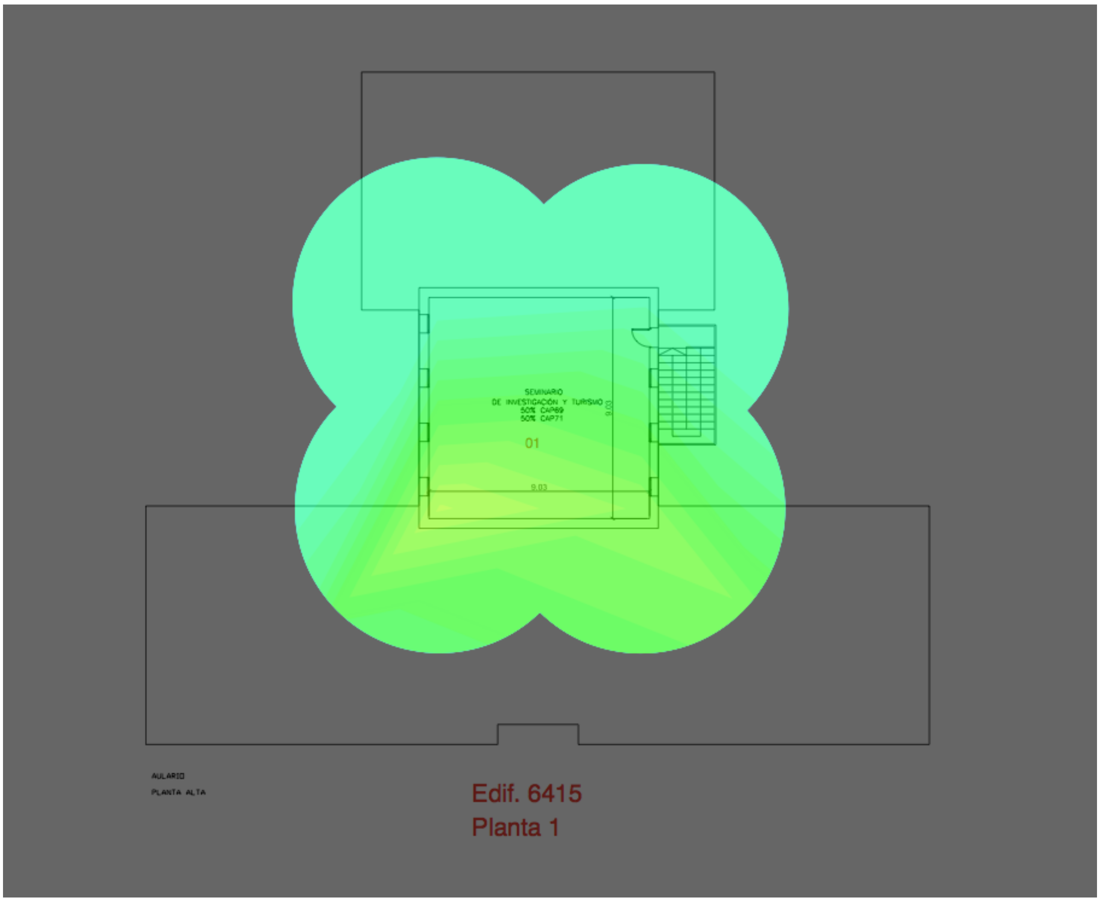


It can be seen that the areas have less coverage.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.6.52.2. Signal Level



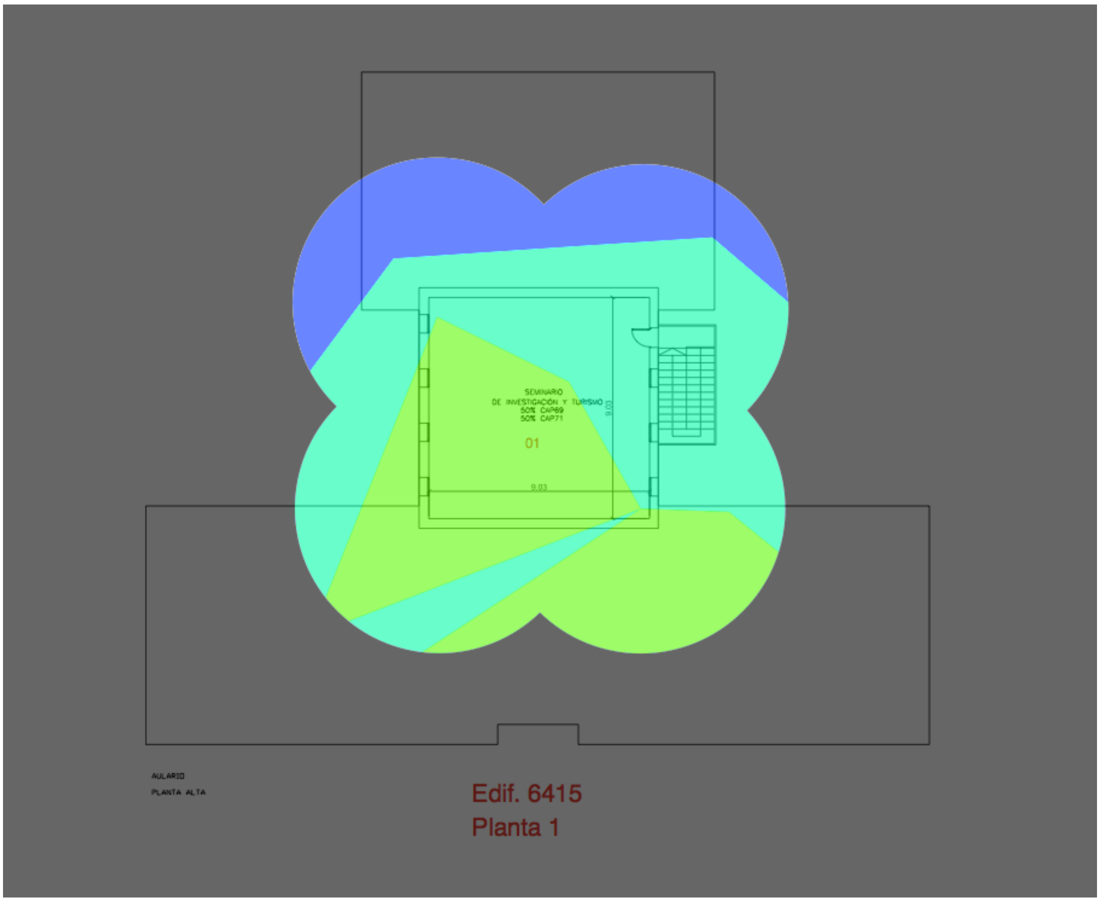
In this picture we can see again how the signal level in the areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

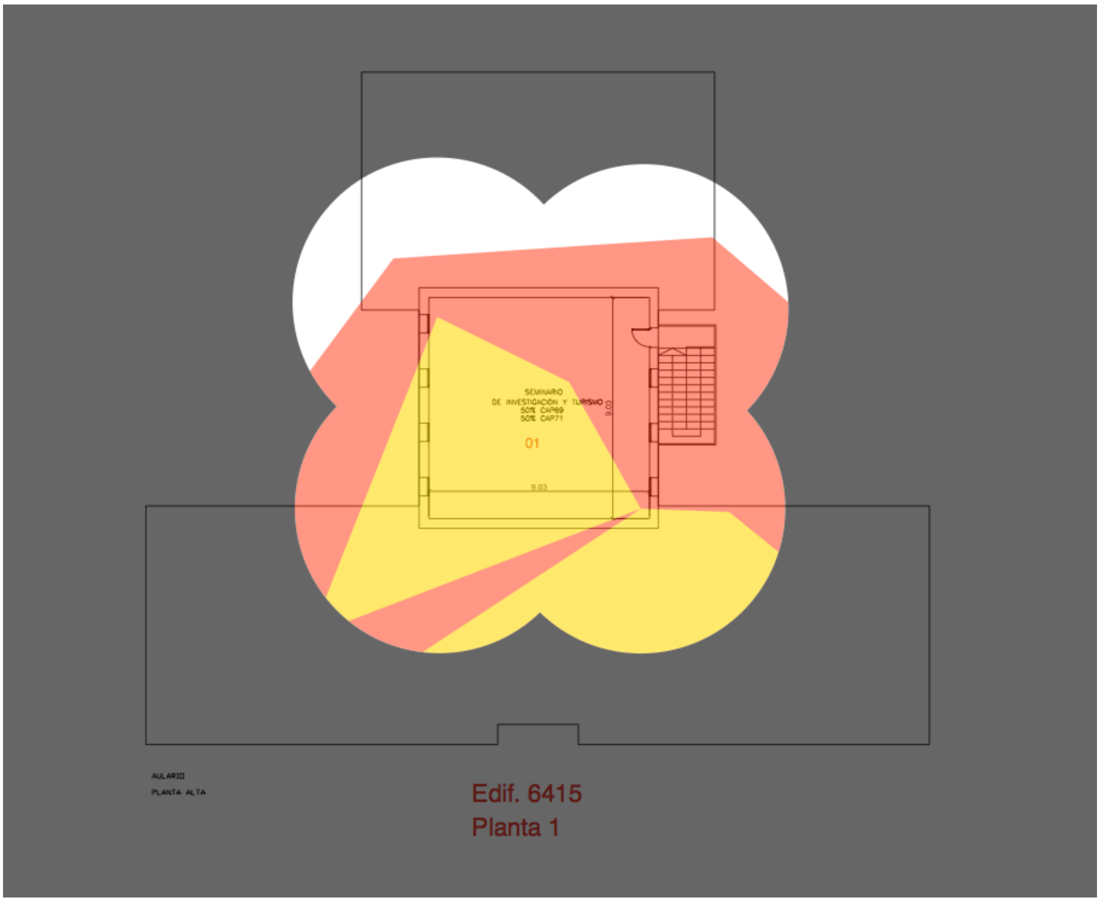
4.6.52.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.6.52.4. Coverage per Frequency Band



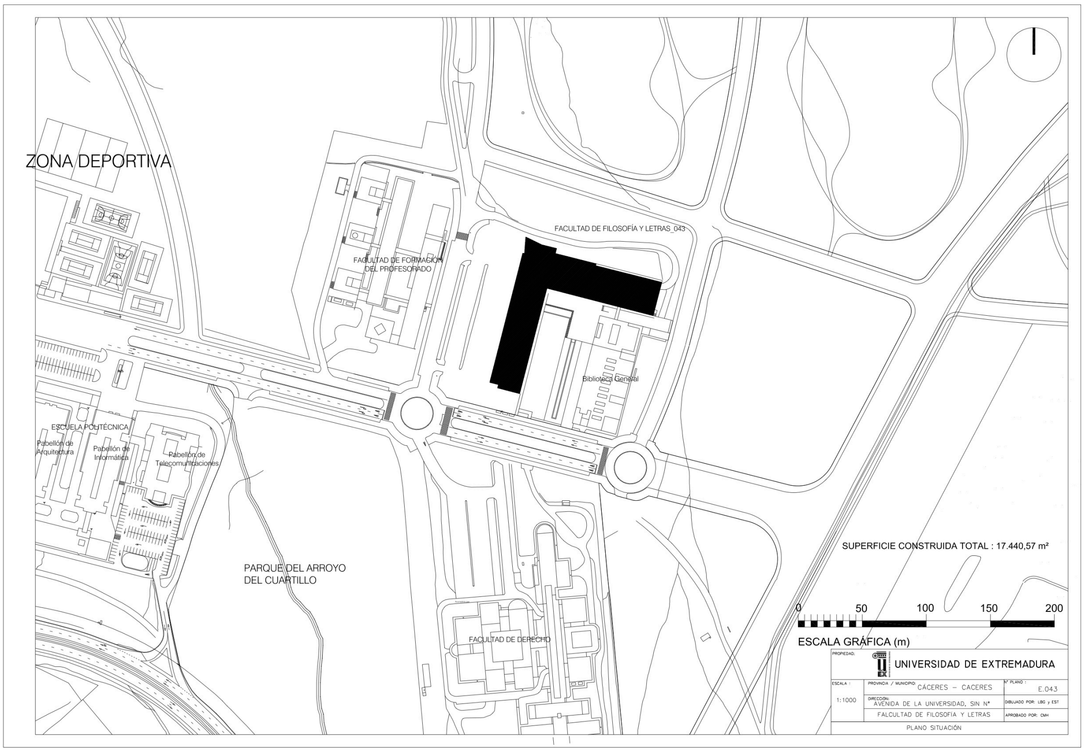
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.7. Facultad de Filosofía y Letras.

A total of 294 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

We see the location of the faculty on the following plan.



4.7.1. Building 0401 Floor 0

4.7.1.1. Signal to Noise Ratio

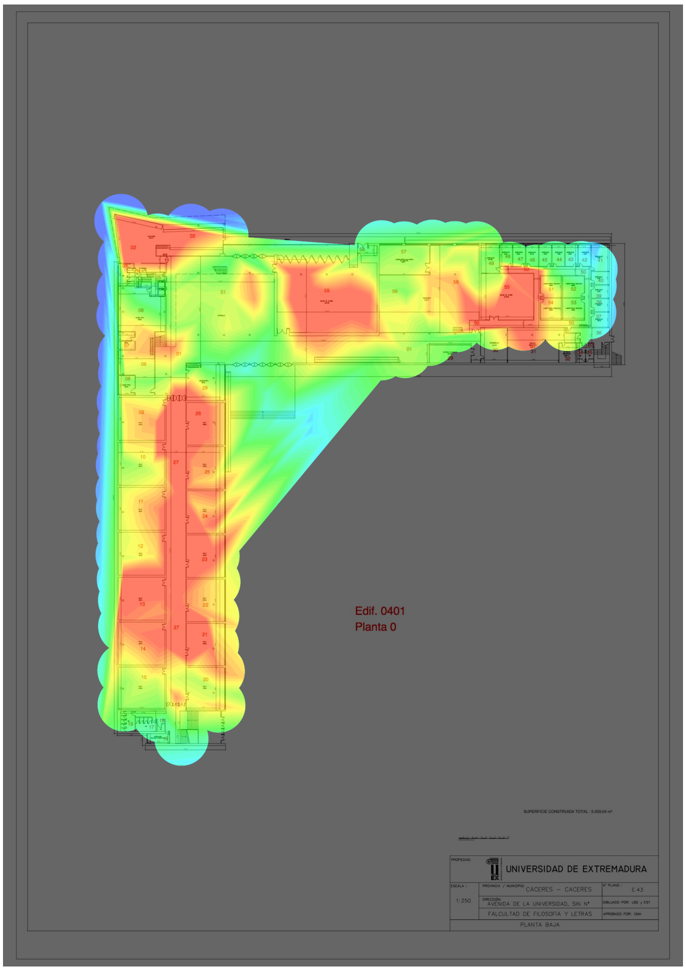
In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.7.1.2. Signal Level



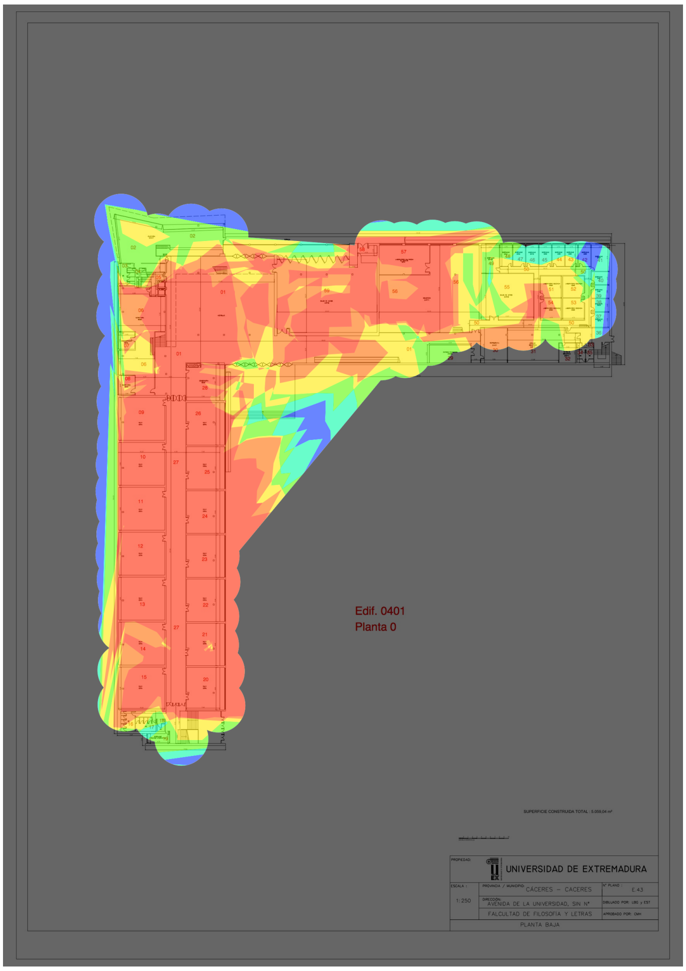
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.7.1.3. Number of Access Points

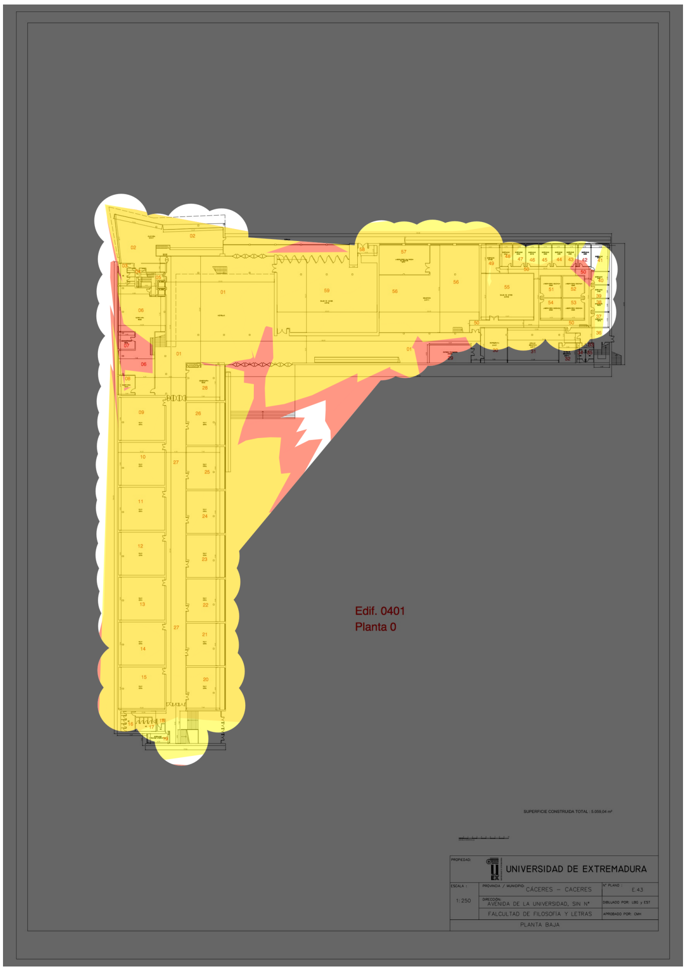


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.7.1.4. Coverage per Frequency Band



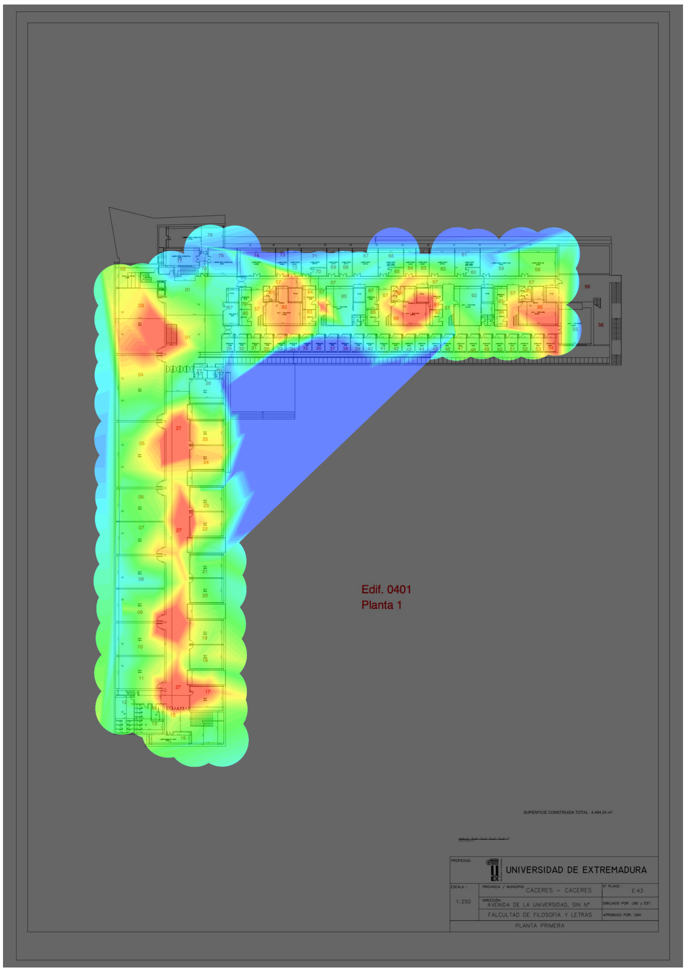
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.7.2. Building 0401 Floor 0

4.7.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

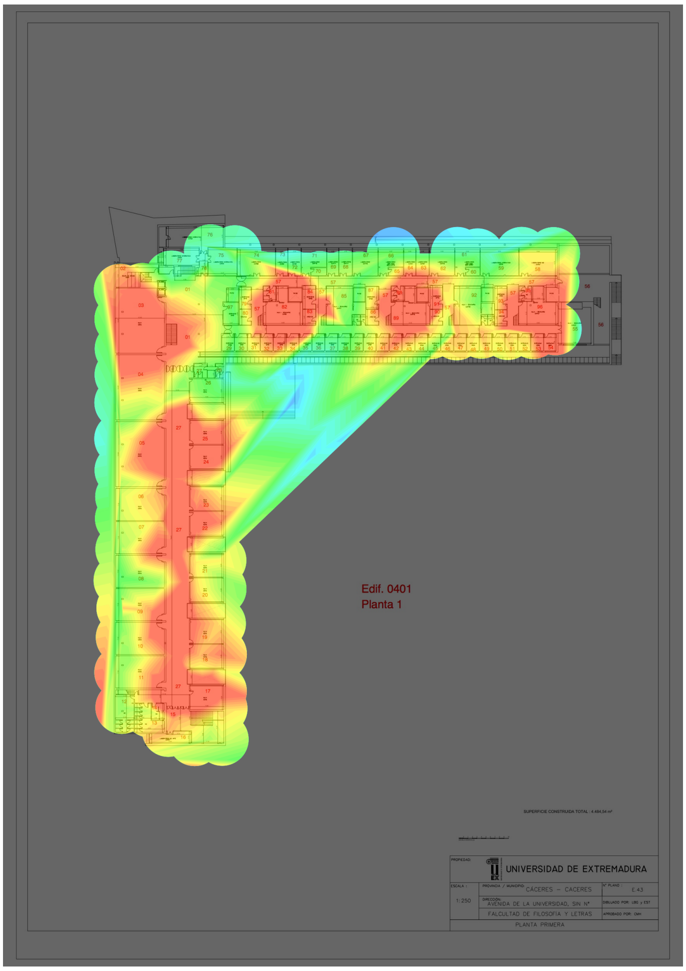


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.7.2.2. Signal Level



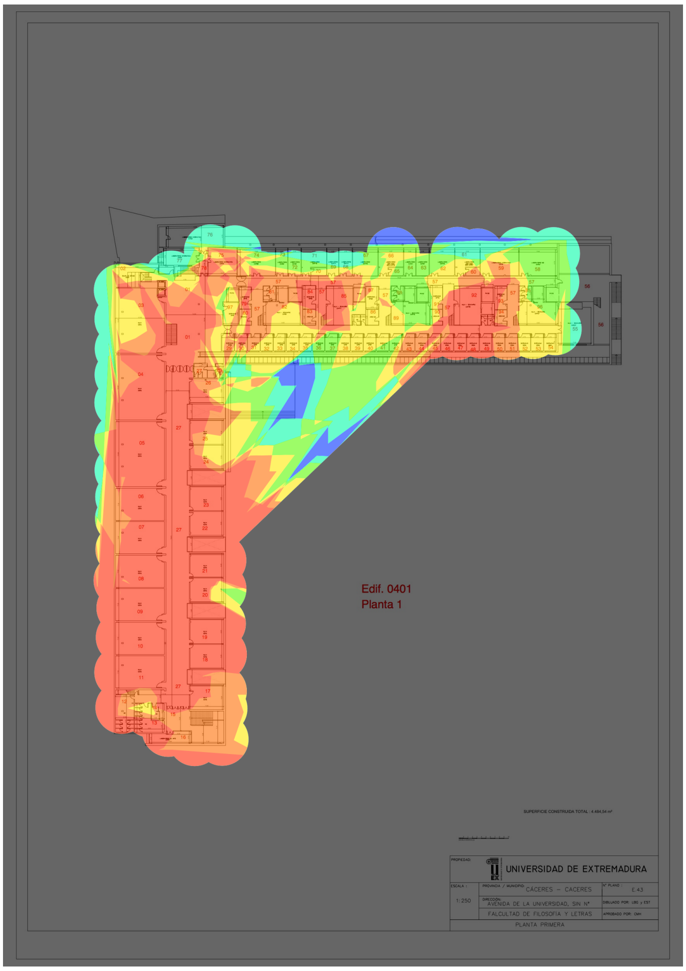
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.7.2.3. Number of Access Points

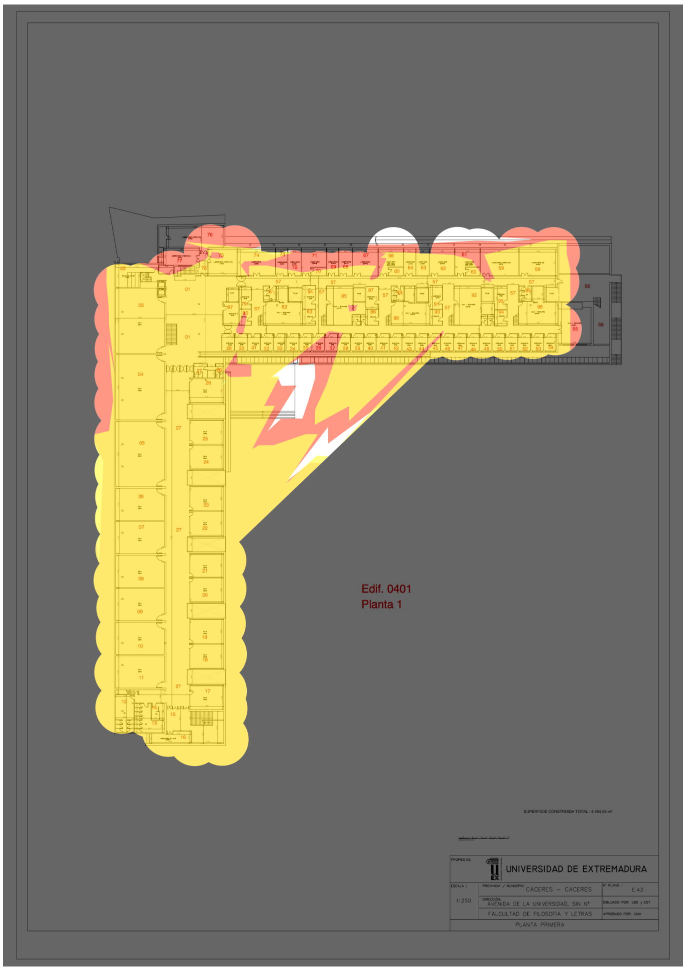


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.7.2.4. Coverage per Frequency Band



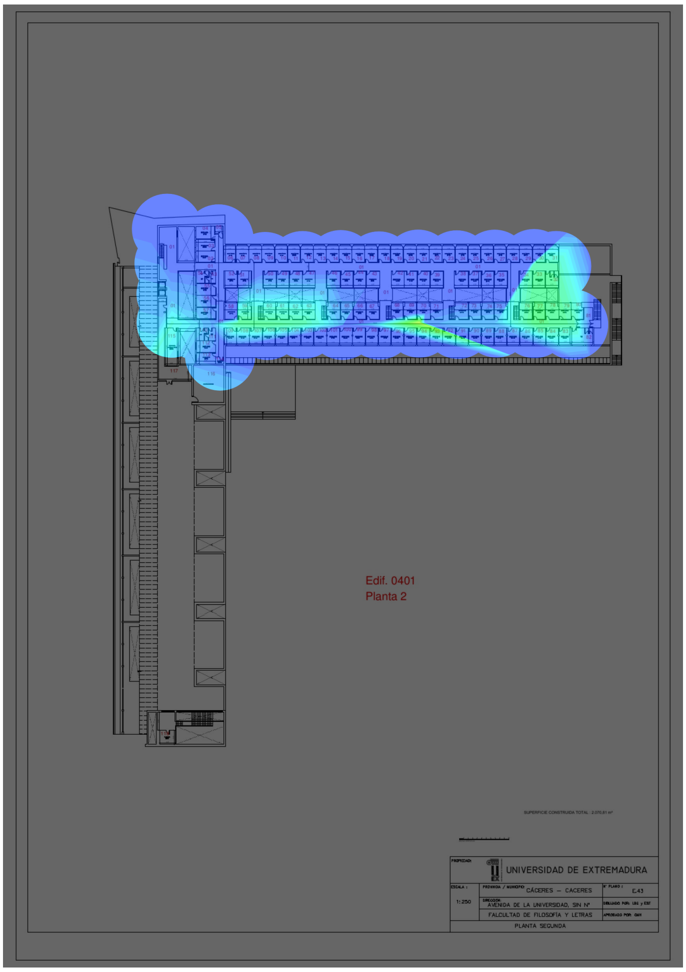
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.7.3. Edificio 0401 Planta 2

4.7.3.1 Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists.

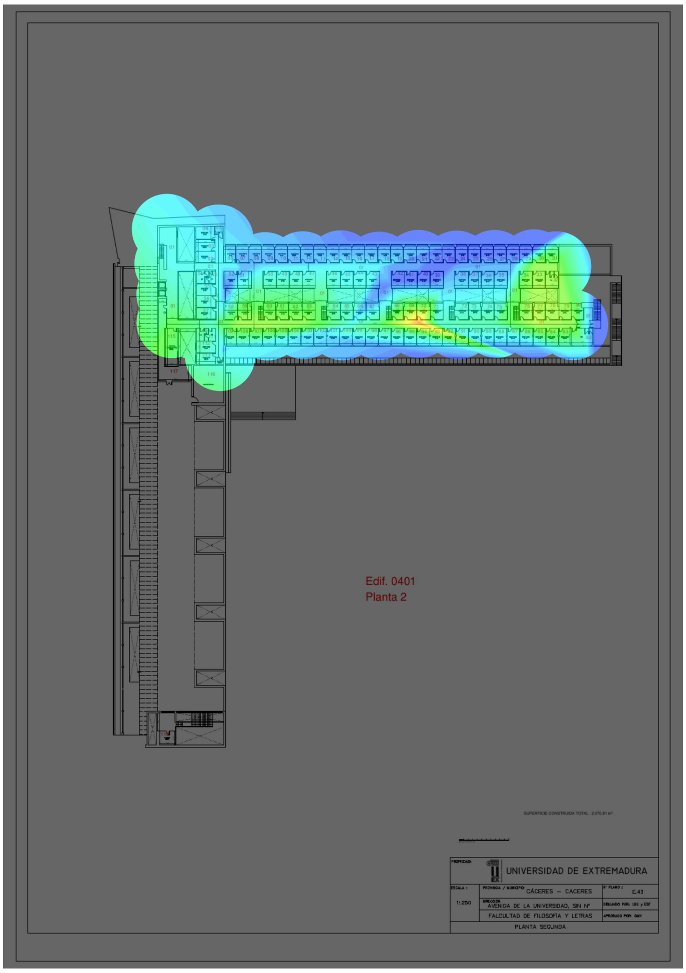


It can be seen that the areas where some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.7.3.2. Signal Level



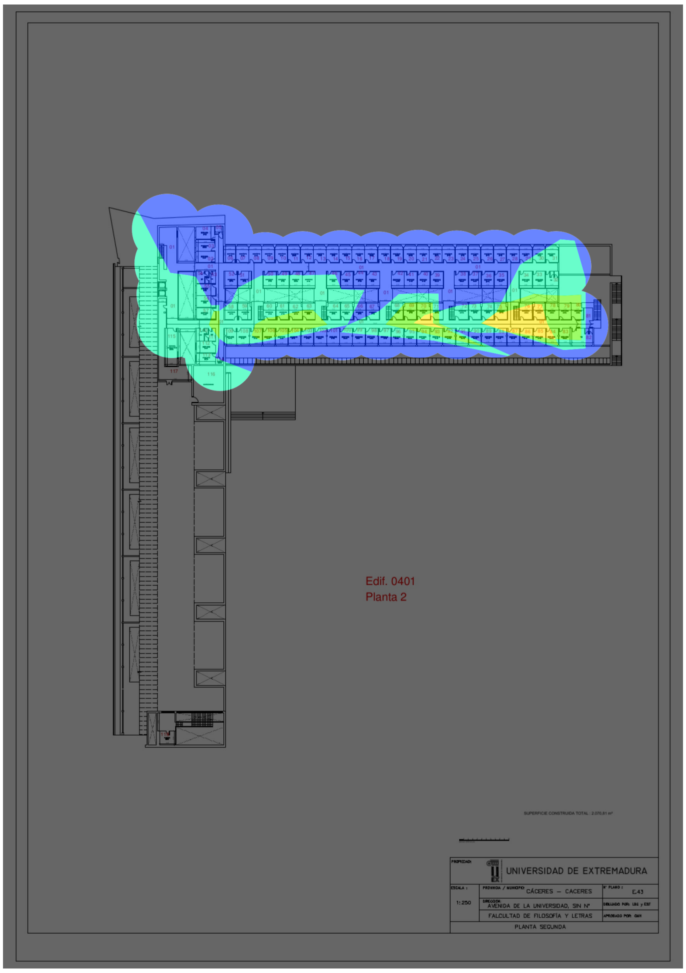
In this picture we can see again how the signal level in some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.7.3.3. Number of Access Points

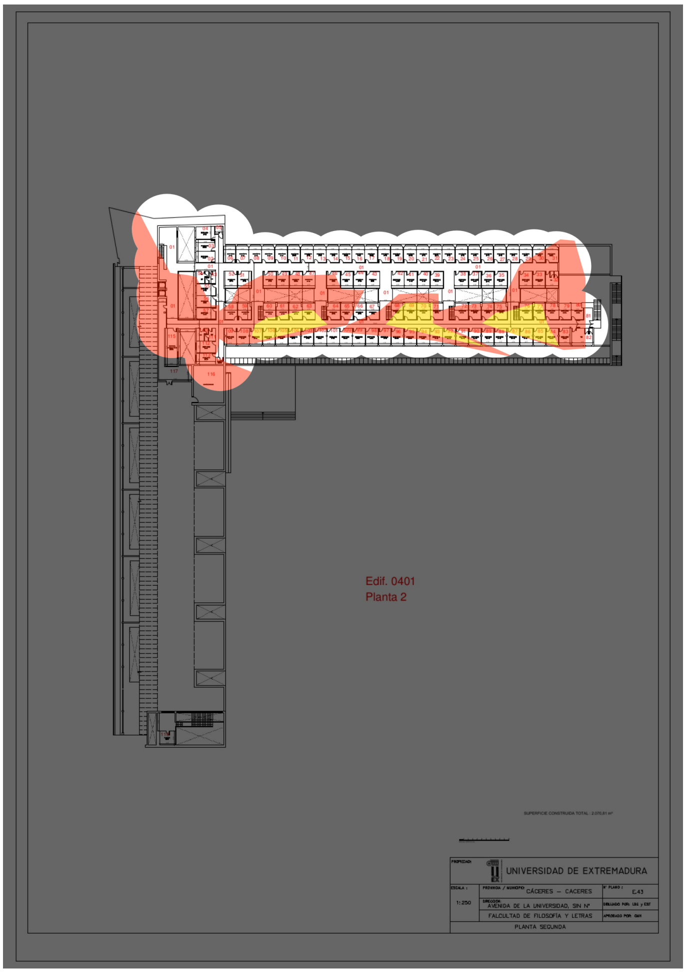


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.7.3.4. Coverage per Frequency Band



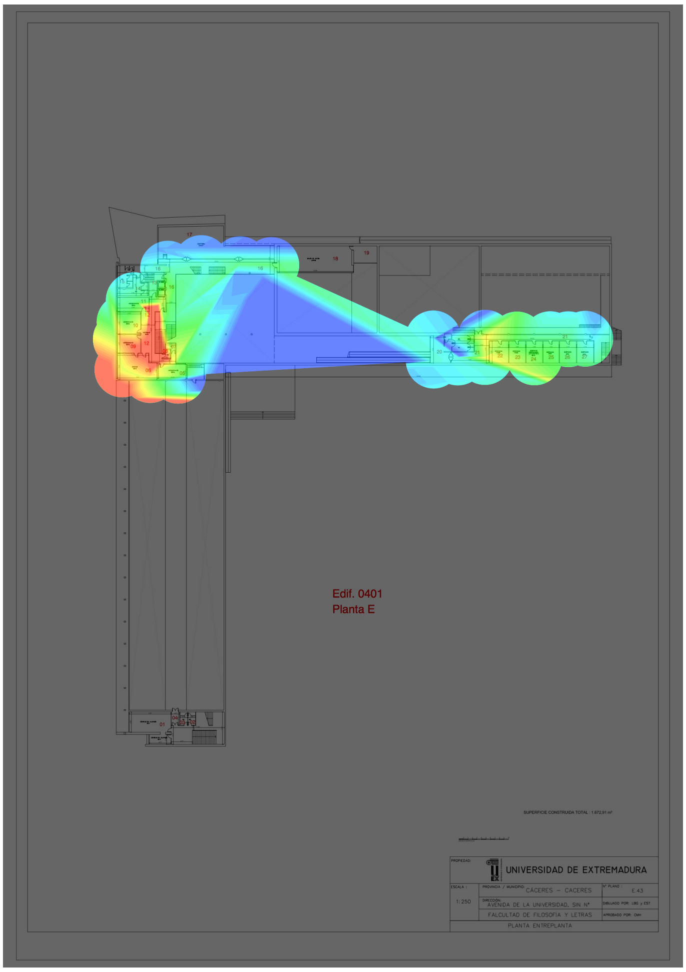
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.7.4. Building 0401 Floor E

4.7.4.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

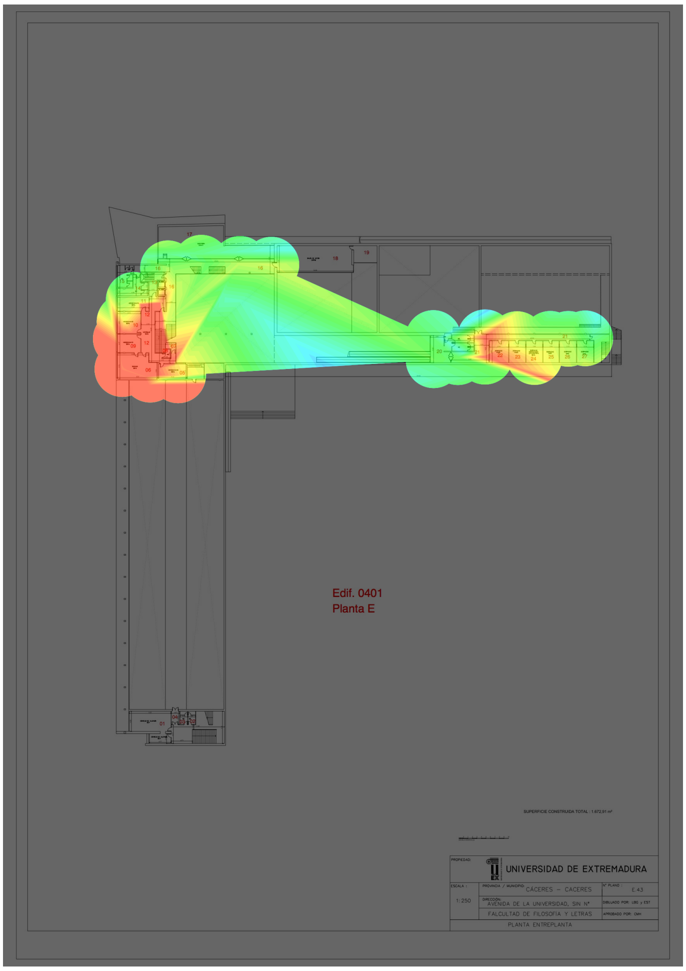


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.7.4.2. Signal Level



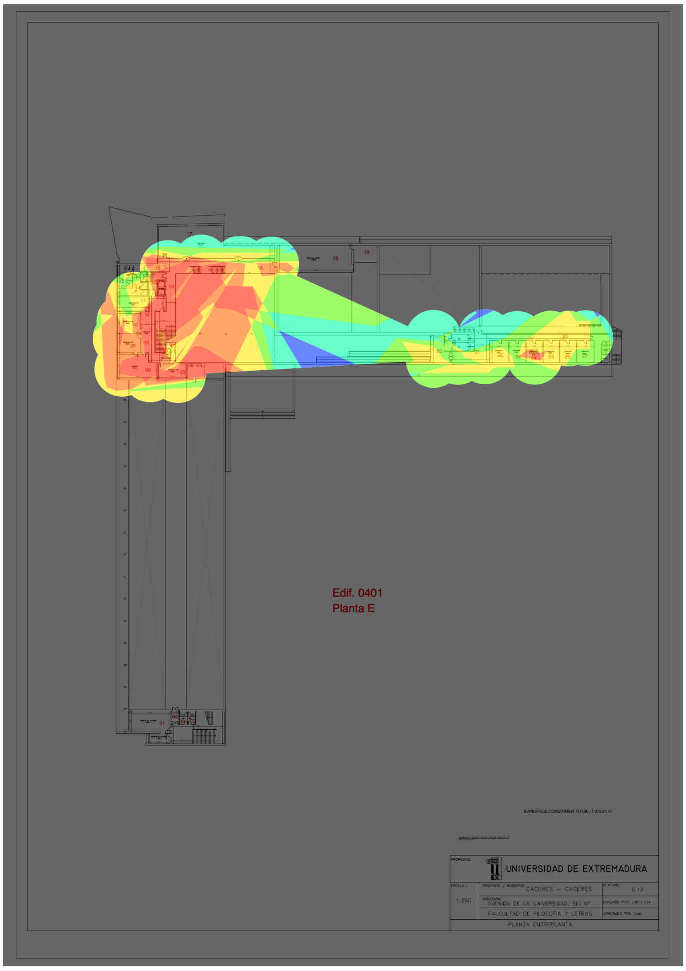
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.7.4.3. Number of Access Points

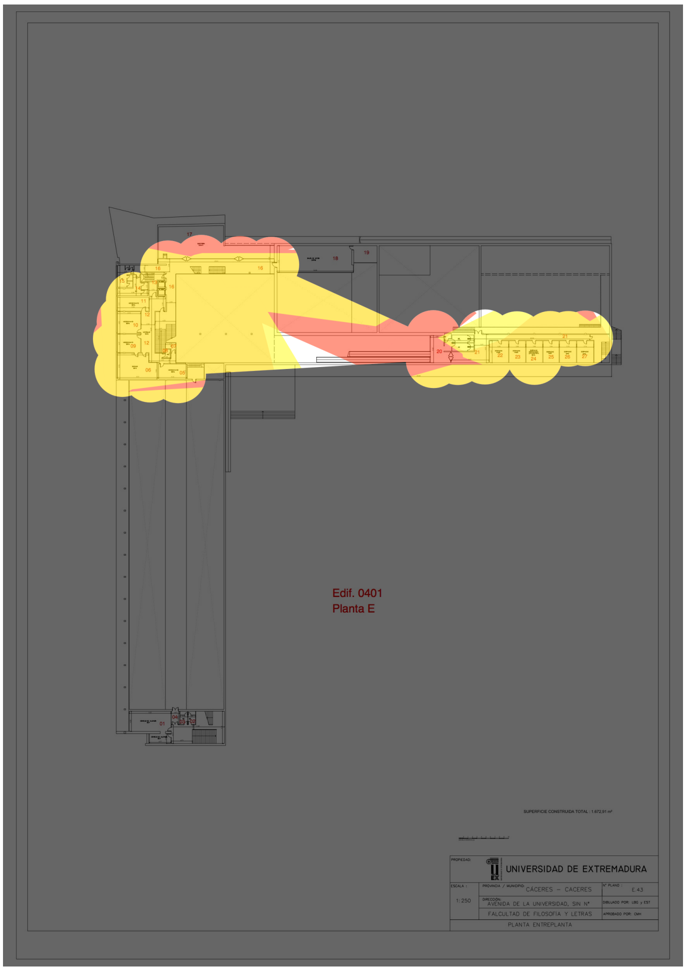


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.7.4.4. Coverage per Frequency Band



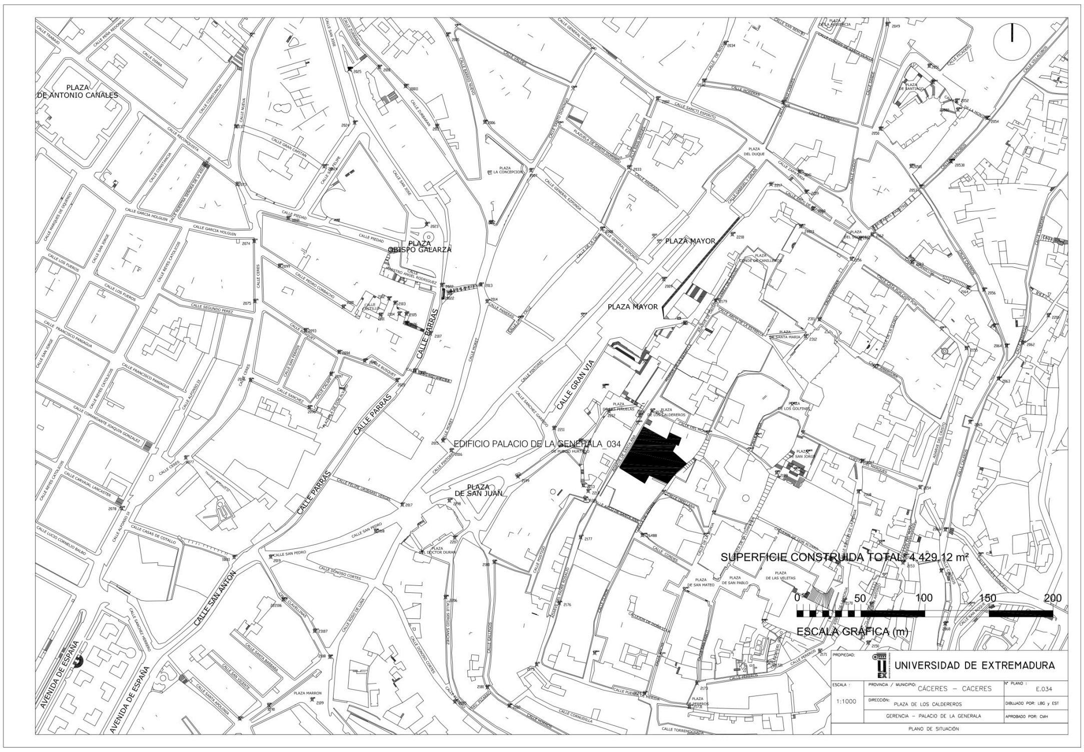
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.8. Palacio de la Generala

A total of 135 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

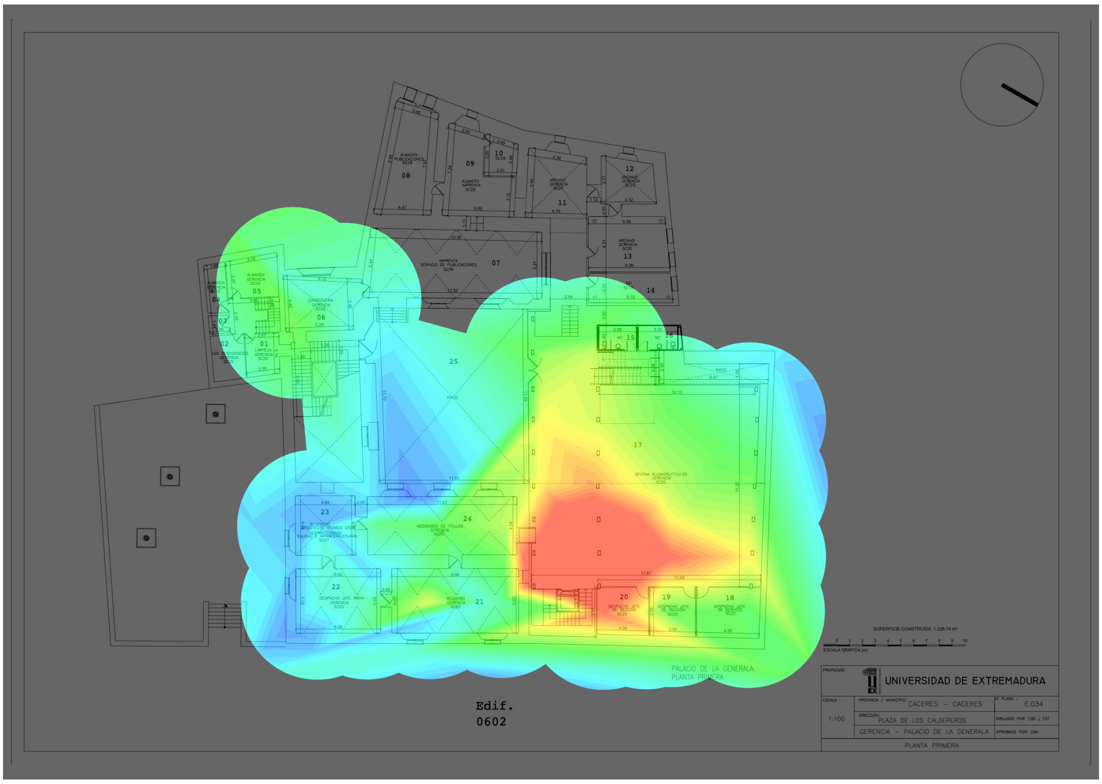
We see the location of the building on the following plan.



4.8.1. Building 0602 Floor 0

4.8.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

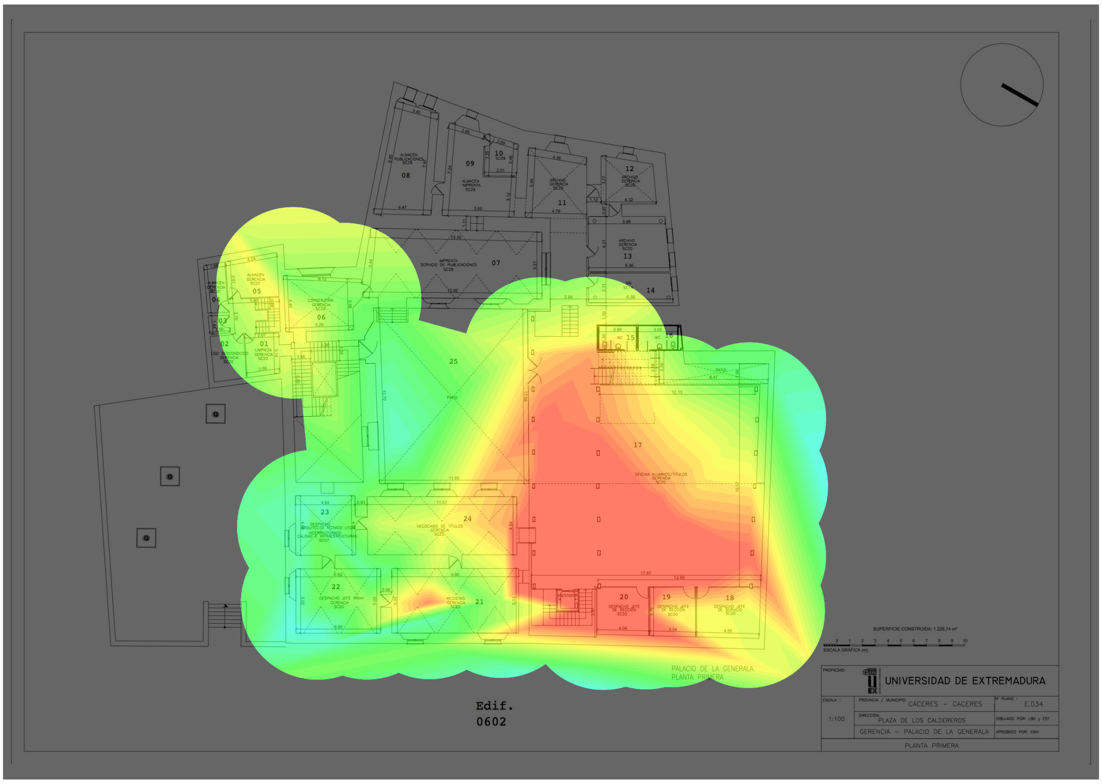


It can be seen that the areas with a good quality signal, and other areas have less coverage.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.8.1.2. Signal Level

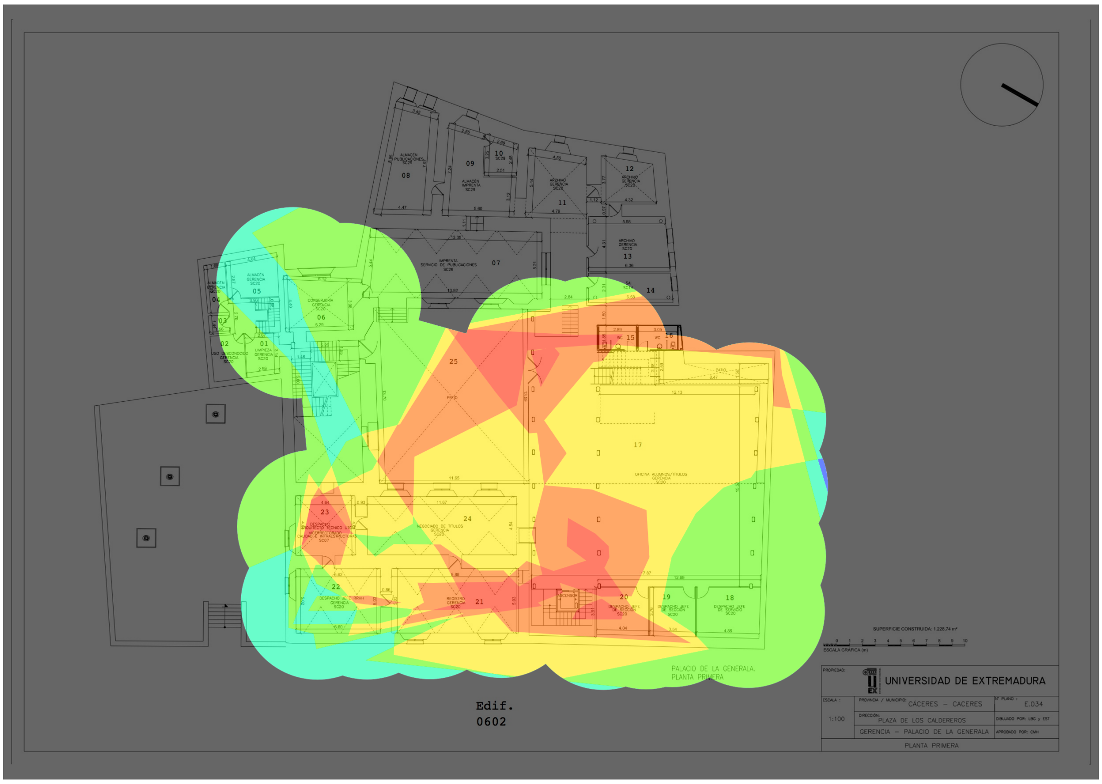


We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

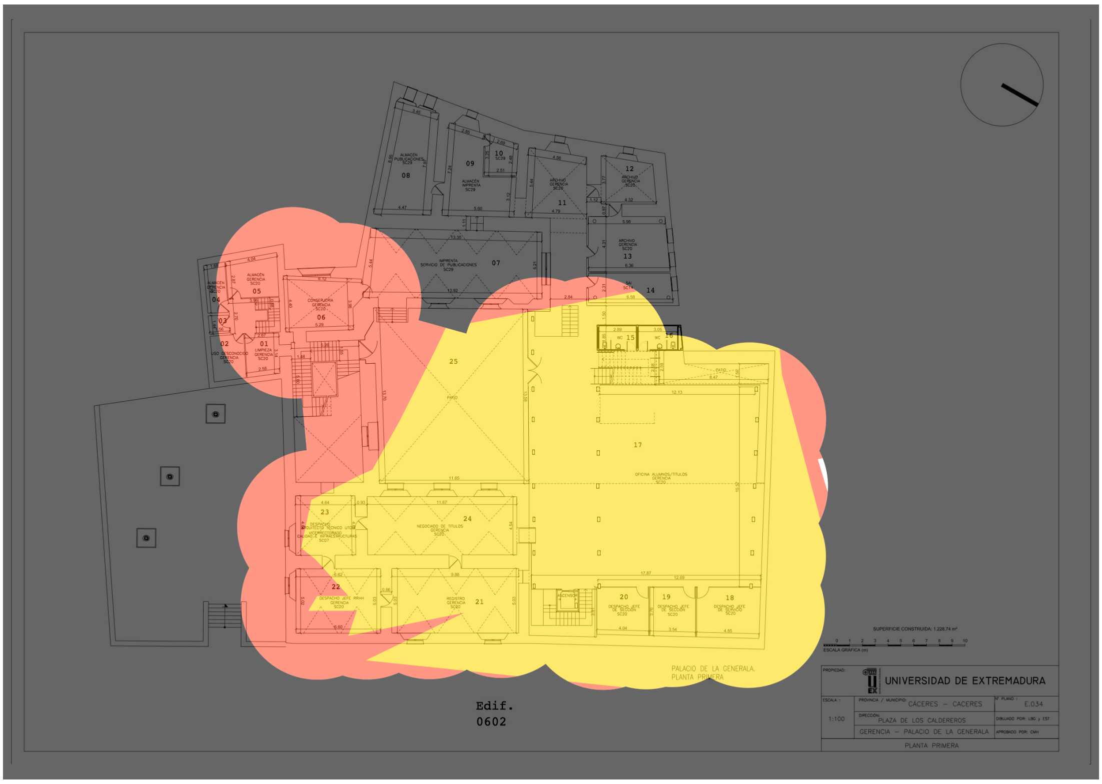
4.8.1.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.8.1.4. Coverage per Frequency Band



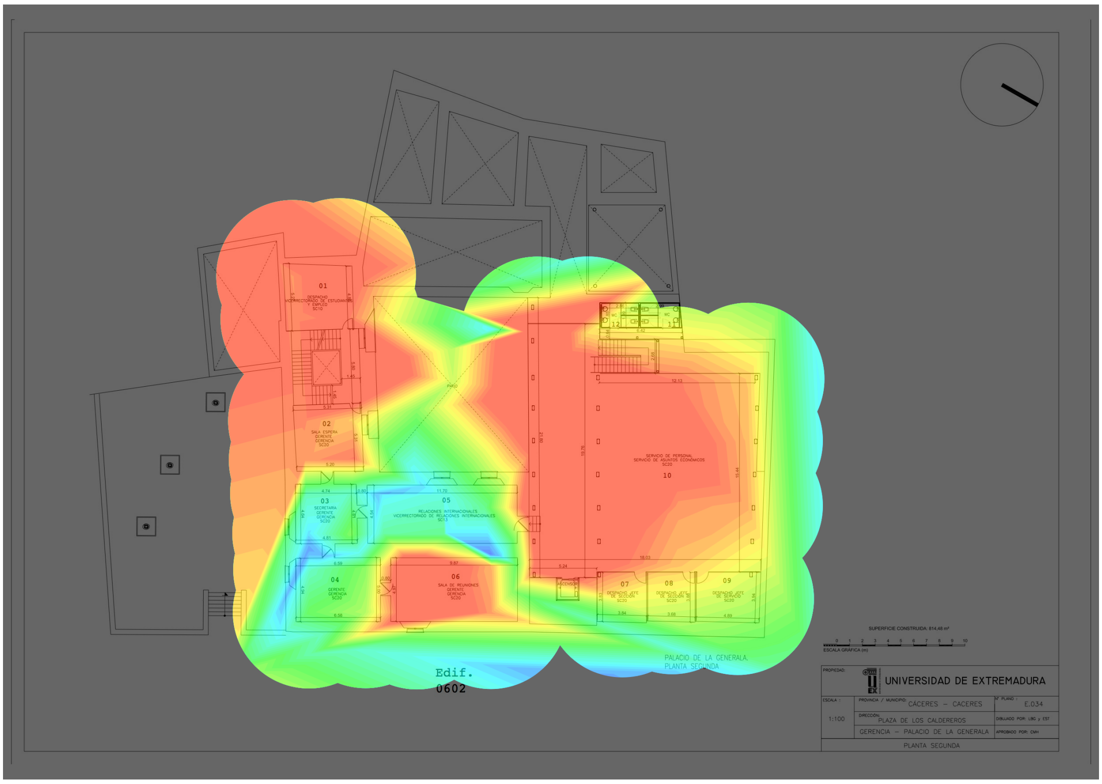
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.8.2. Building 0602 Floor 1

4.8.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

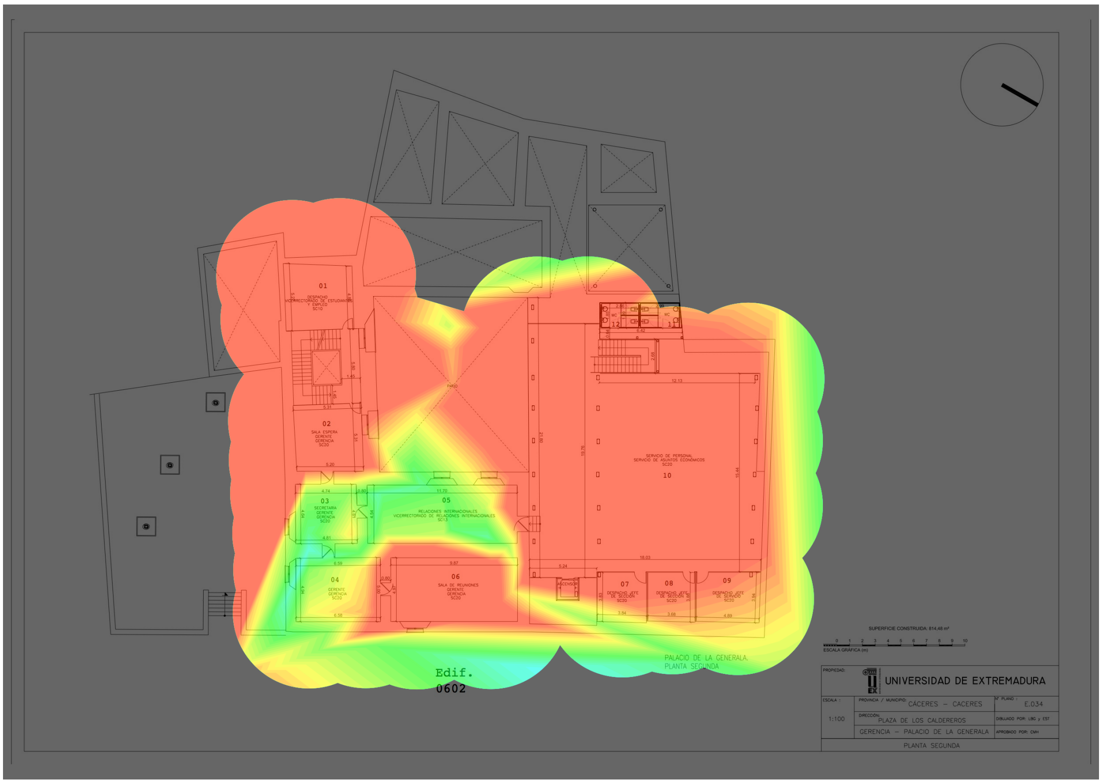


It can be seen that the areas with a good quality signal, and other areas have less coverage.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.8.2.2. Signal Level

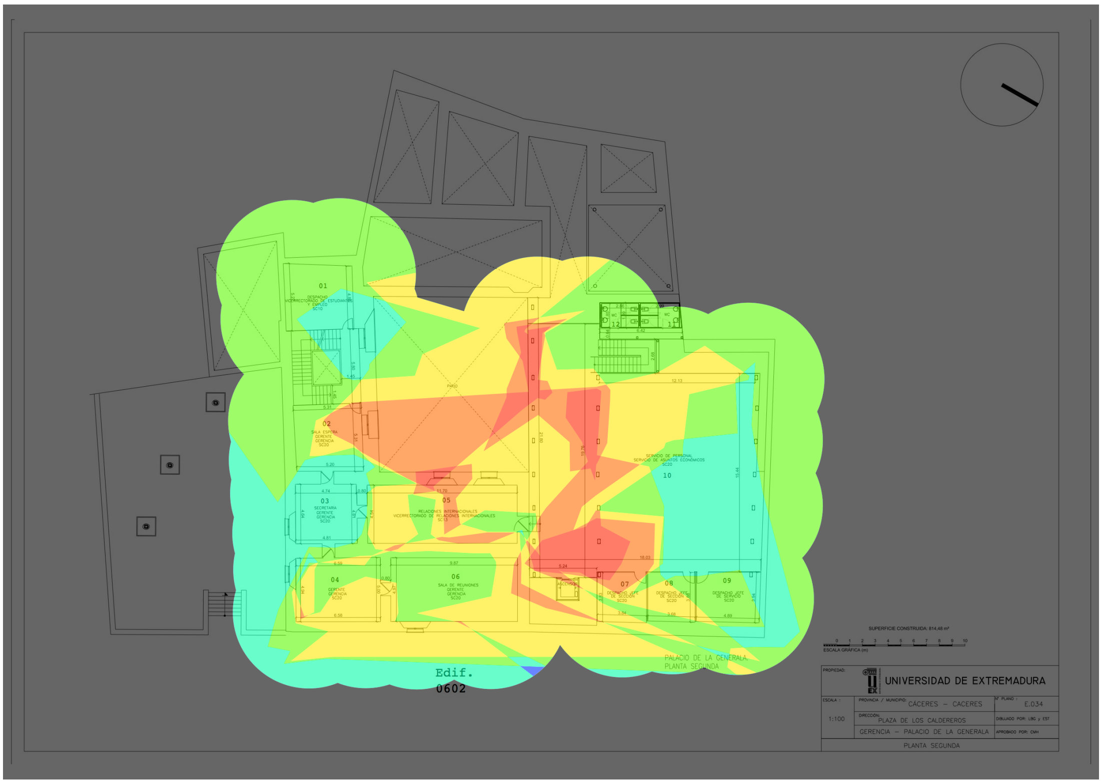


We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

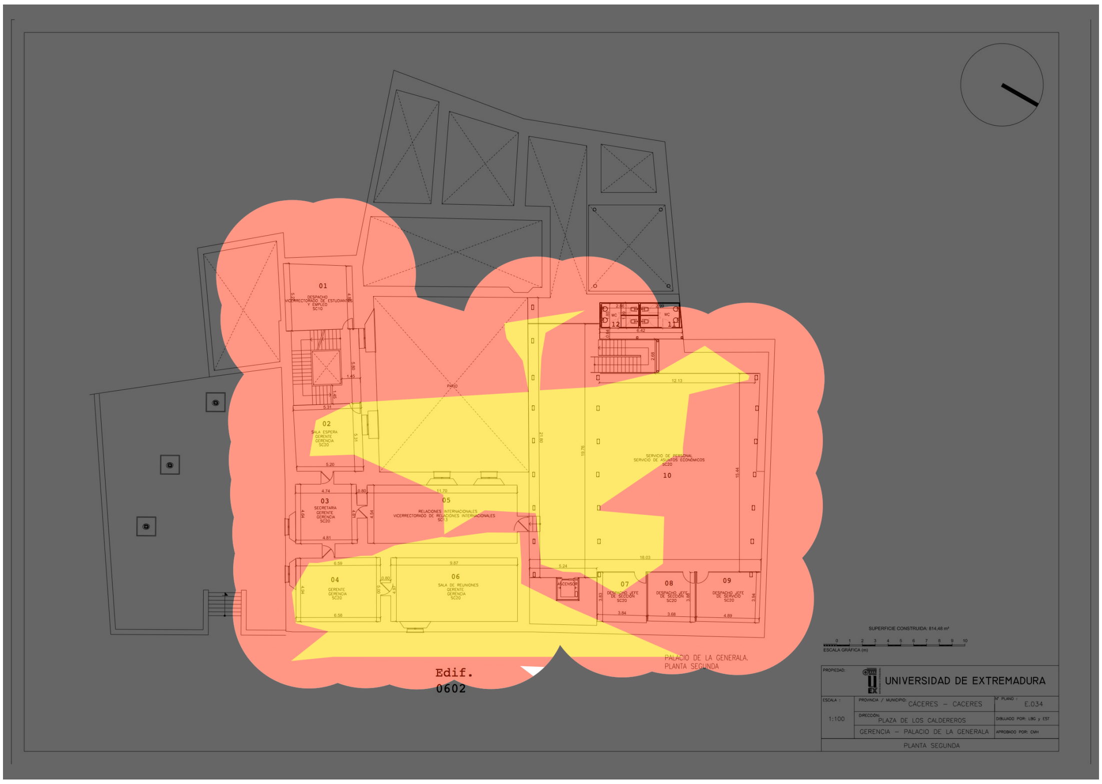
4.8.2.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.8.2.4. Coverage per Frequency Band



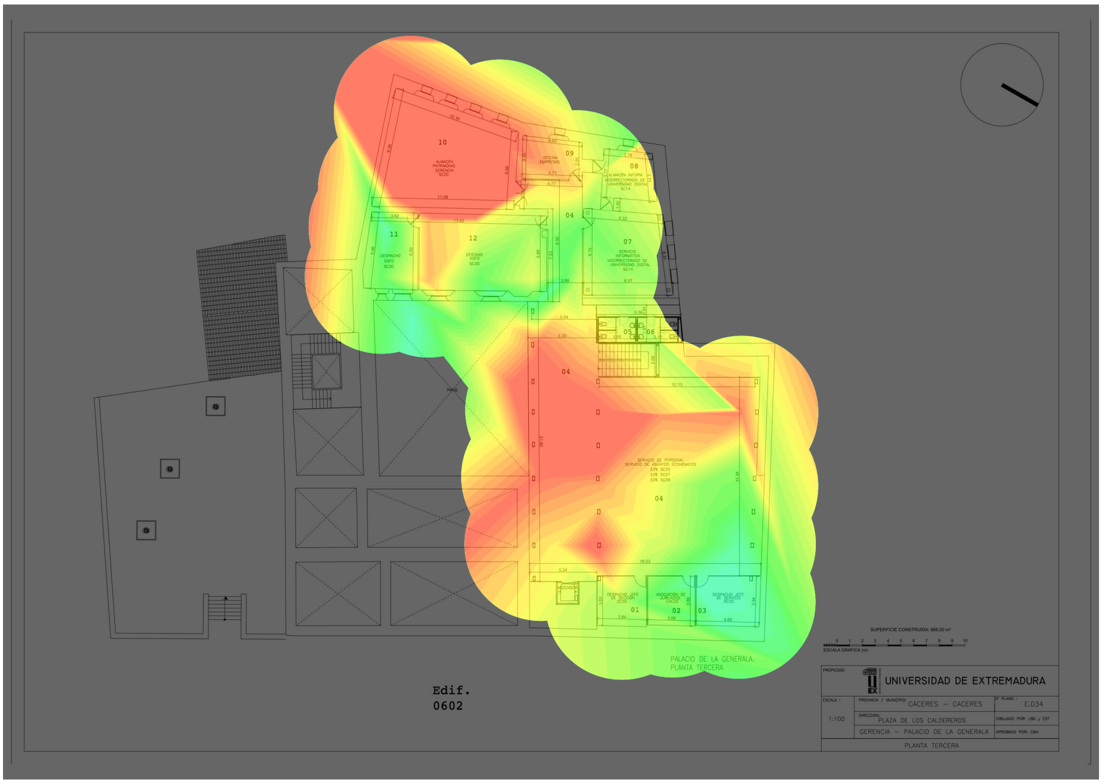
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.8.3. Building 0602 Floor 2

4.8.3.1. Signal to Noise Ratio

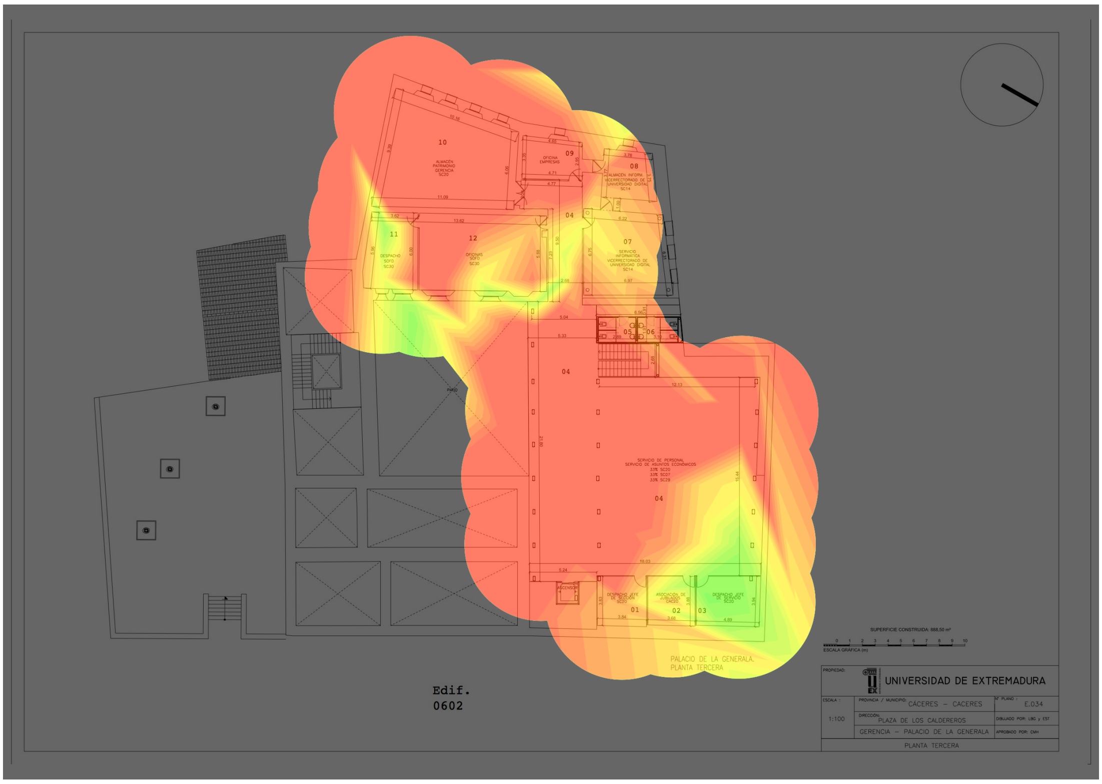
In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.



The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.8.3.2. Signal Level

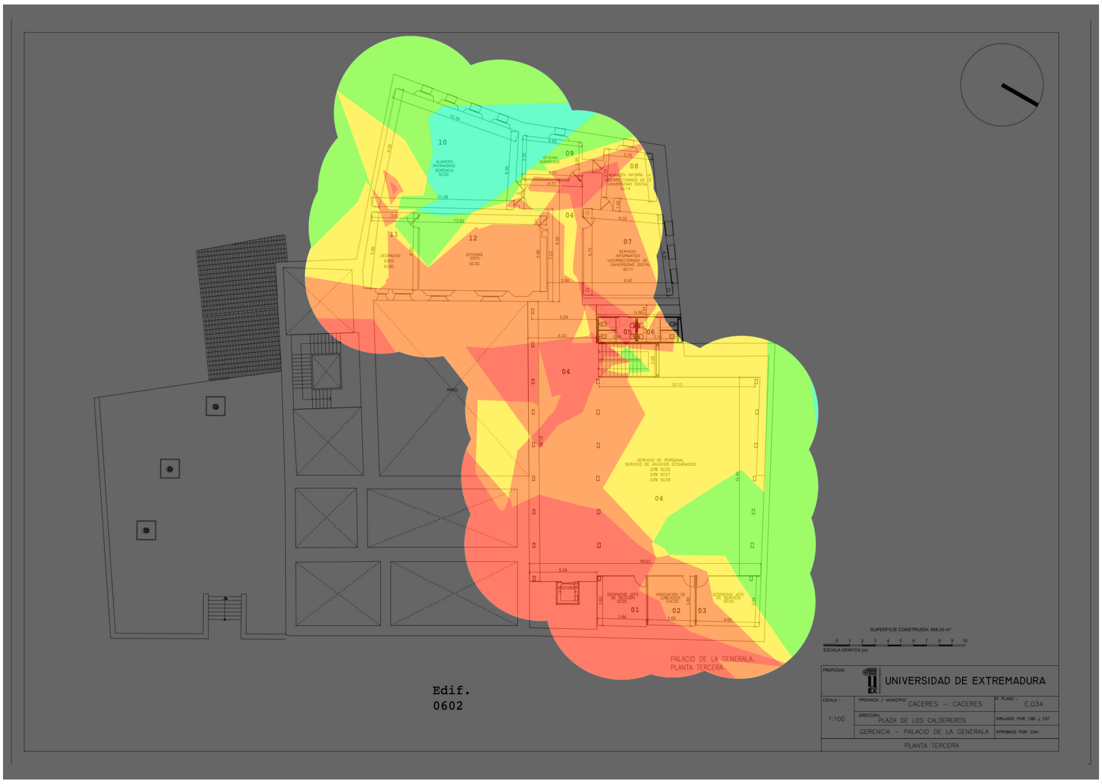


We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

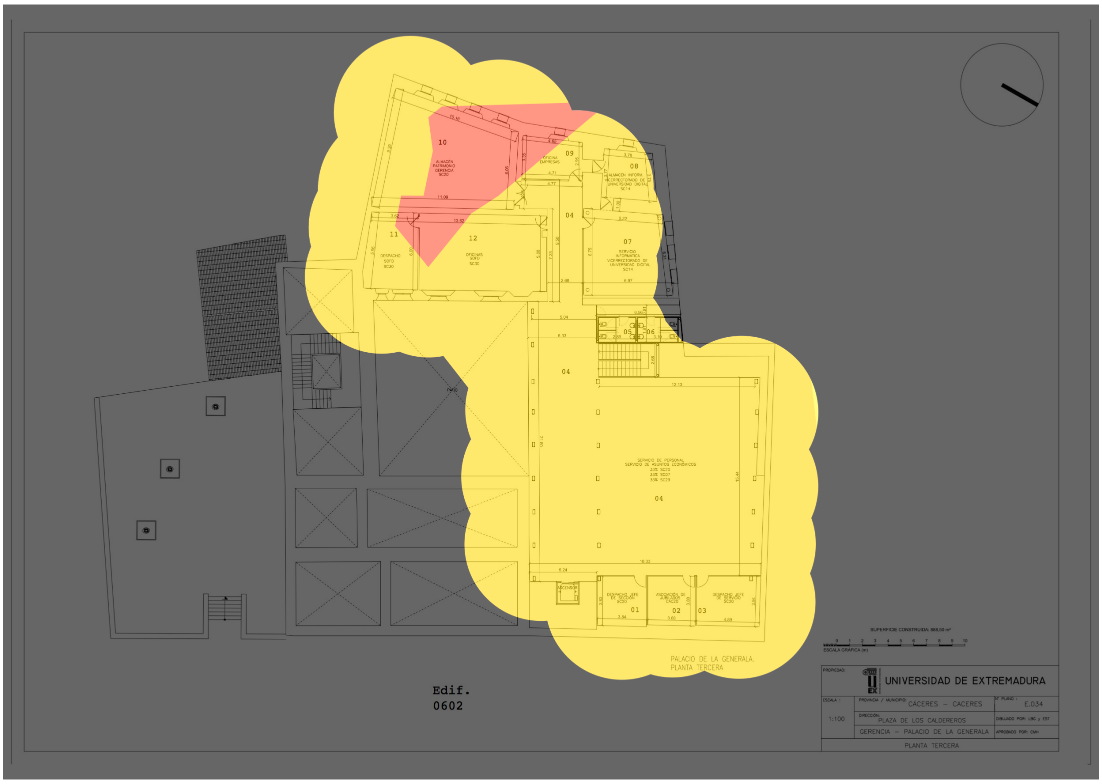
4.8.3.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.8.3.4. Coverage per Frequency Band

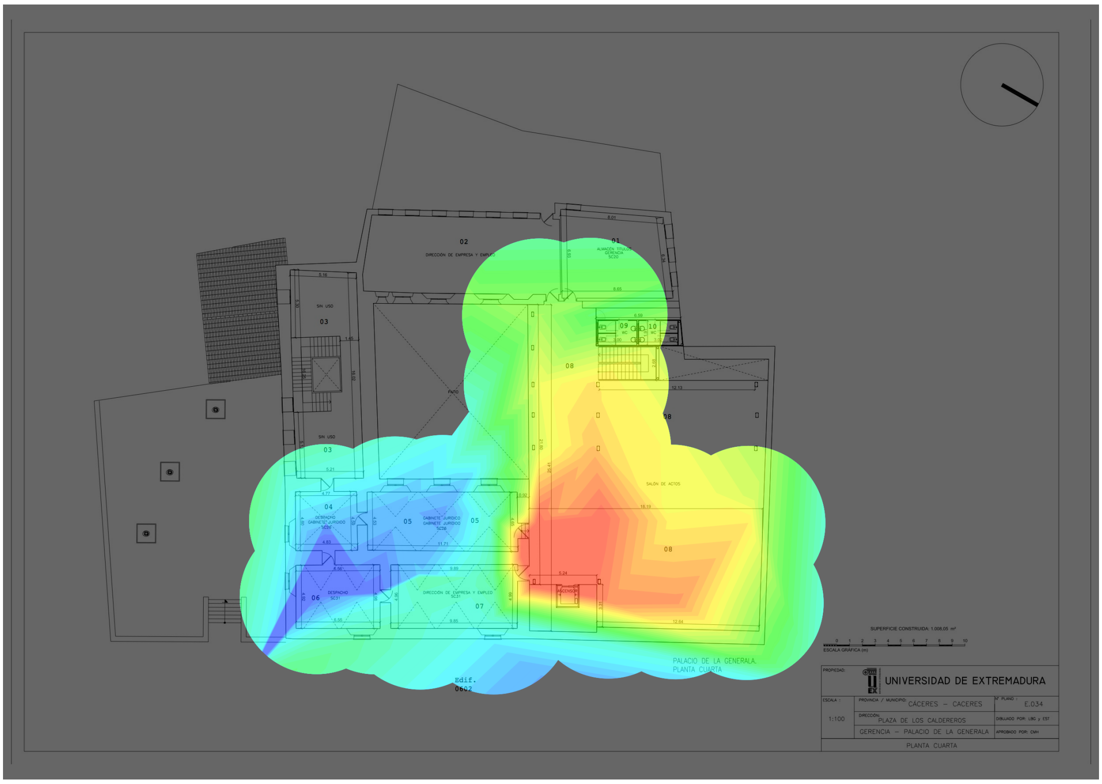


In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

4.8.4. Building 0602 Floor 3

4.8.4.1. Signal to Noise Ratio

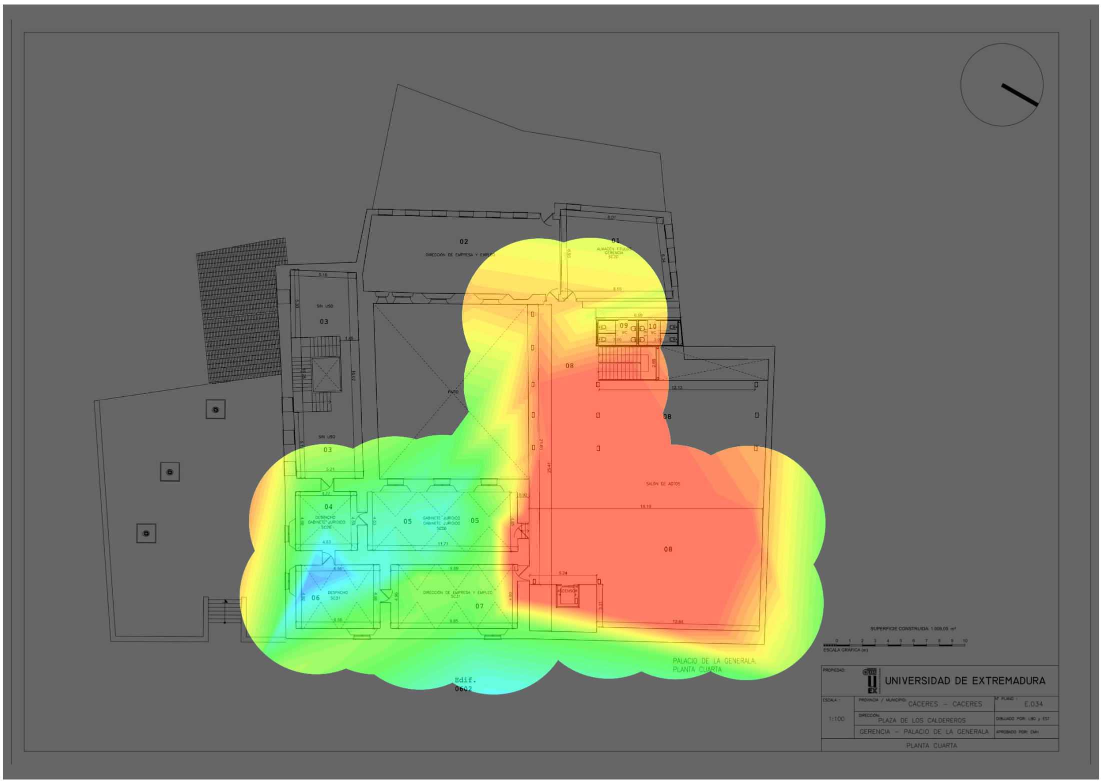
In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.



The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.8.4.2. Signal Level

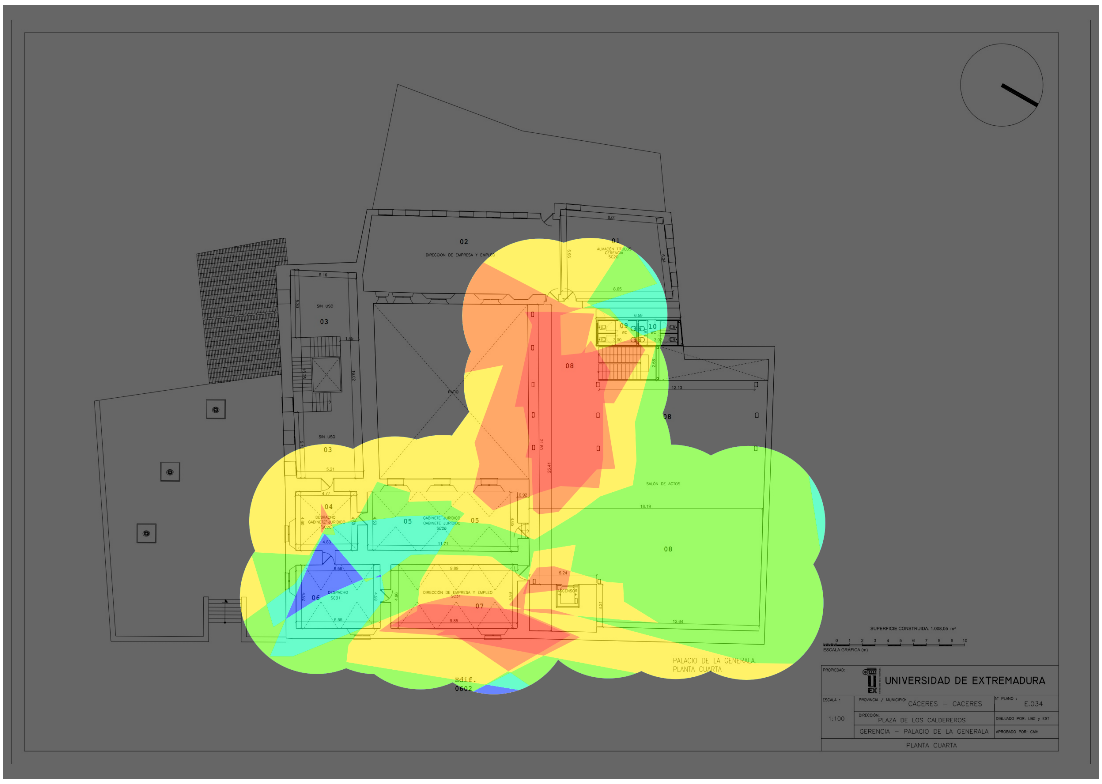


We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

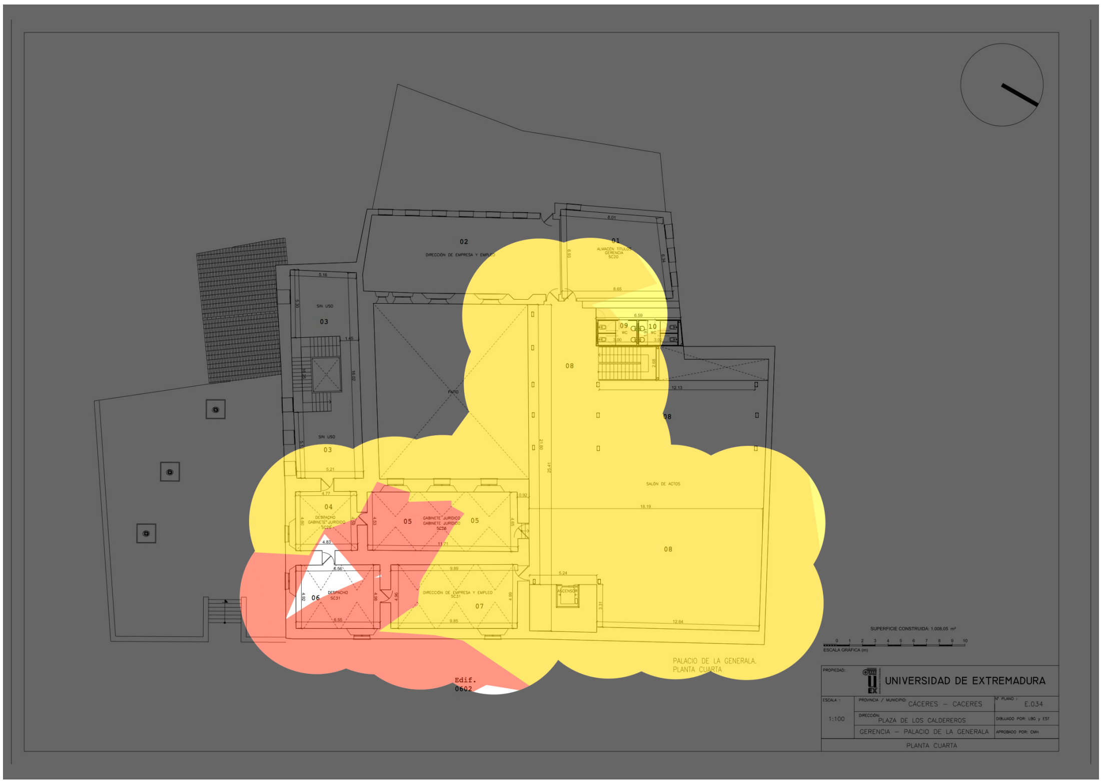
4.8.4.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.8.4.4. Coverage per Frequency Band



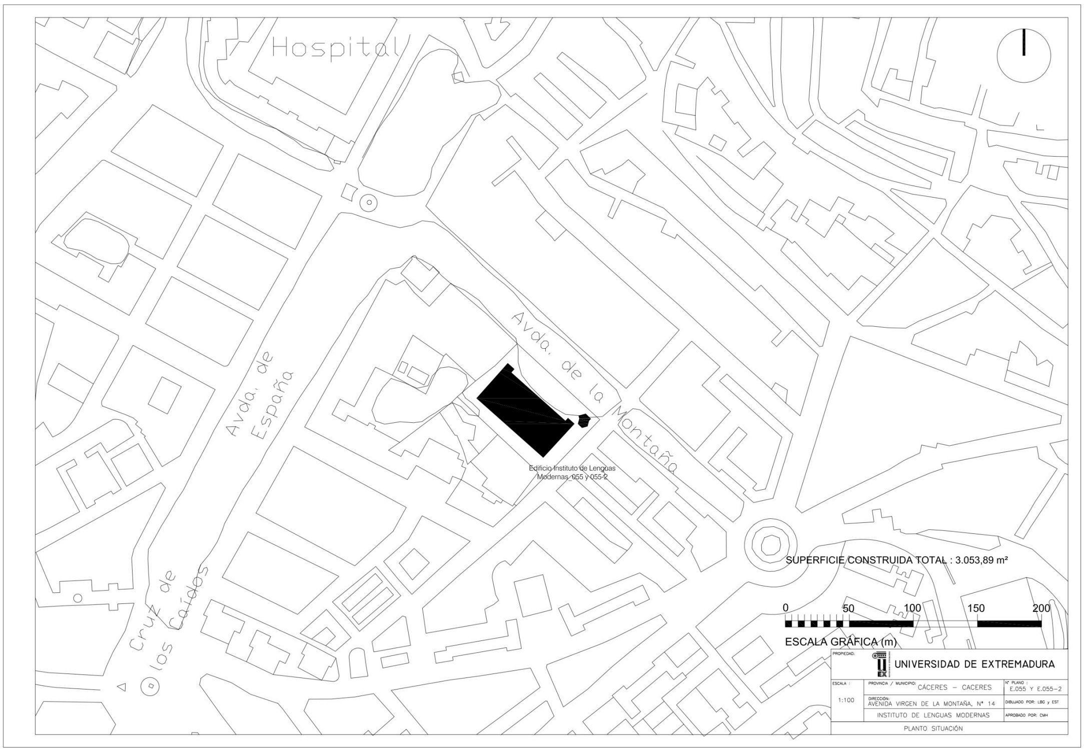
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.9. Instituto de Lenguas Modernas

A total of 100 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

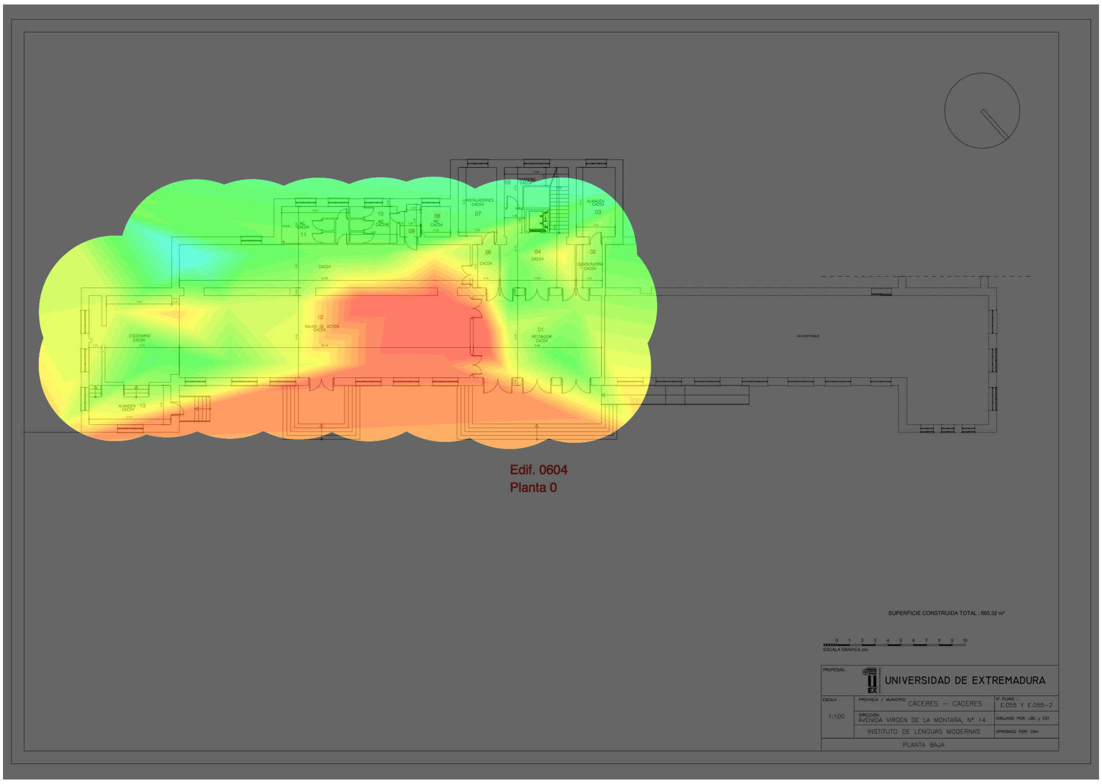
We see the location of the building on the following plan.



4.9.1. Building 0604 Floor 0

4.9.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

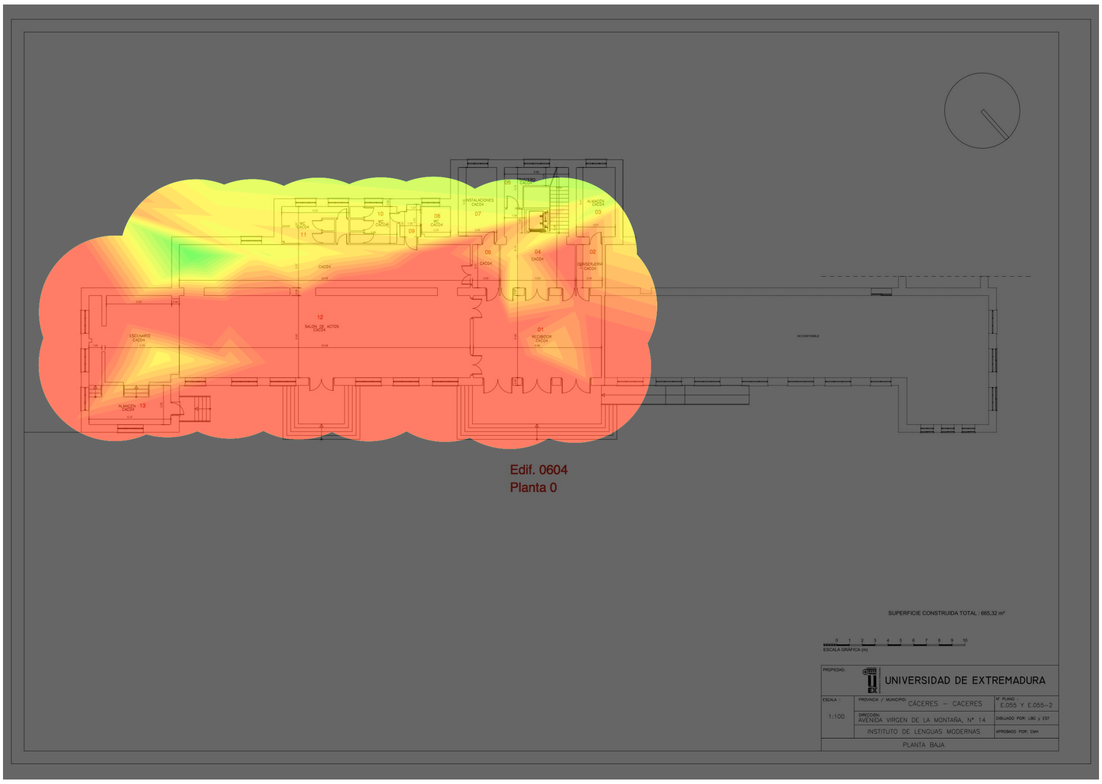


It can be seen that the areas where the classrooms are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.9.1.2. Signal Level



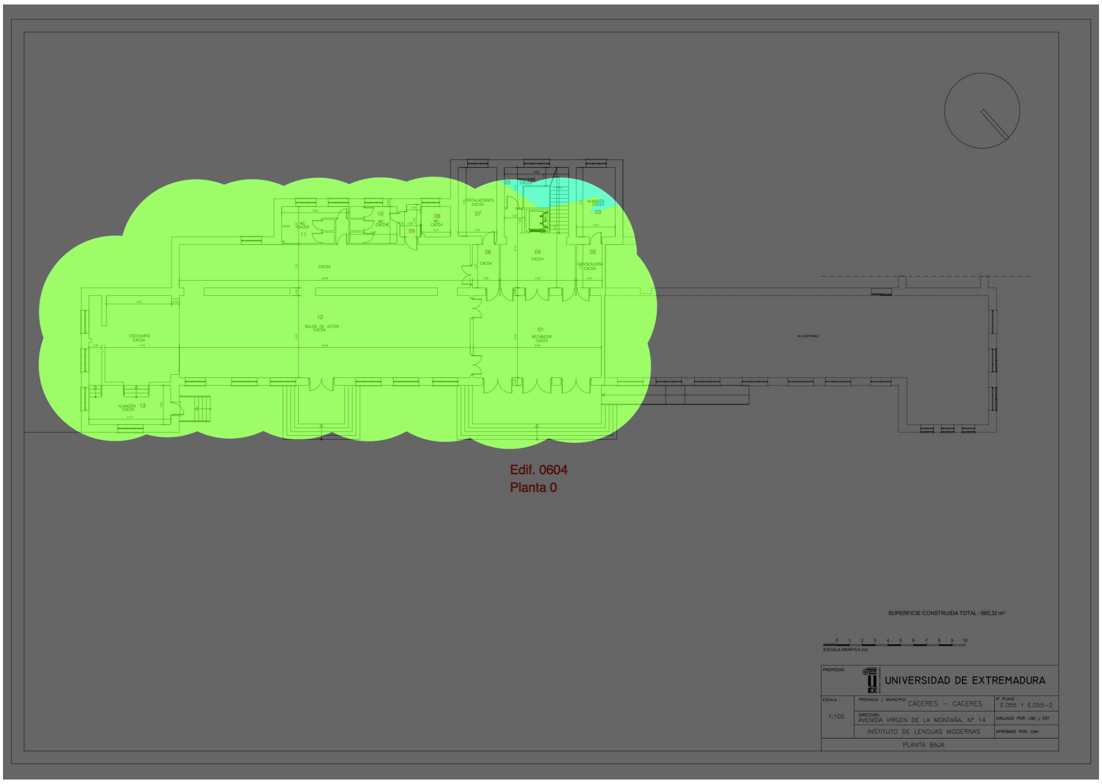
In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

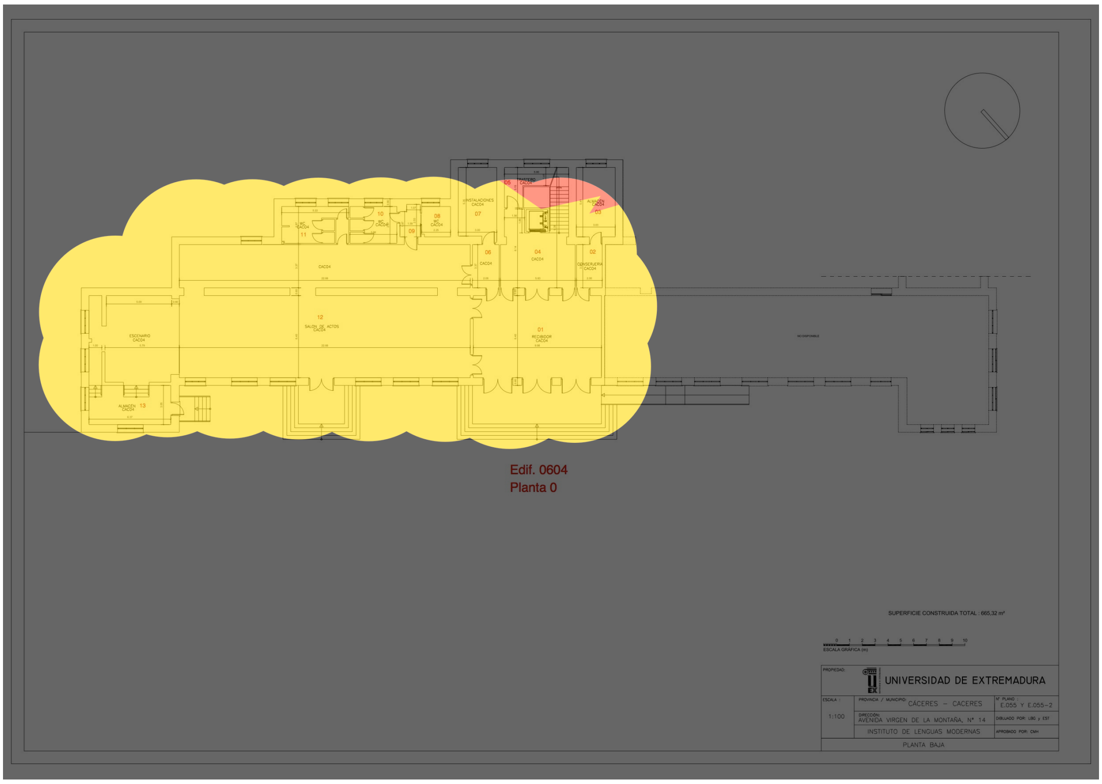
4.9.1.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.9.1.4. Coverage per Frequency Band

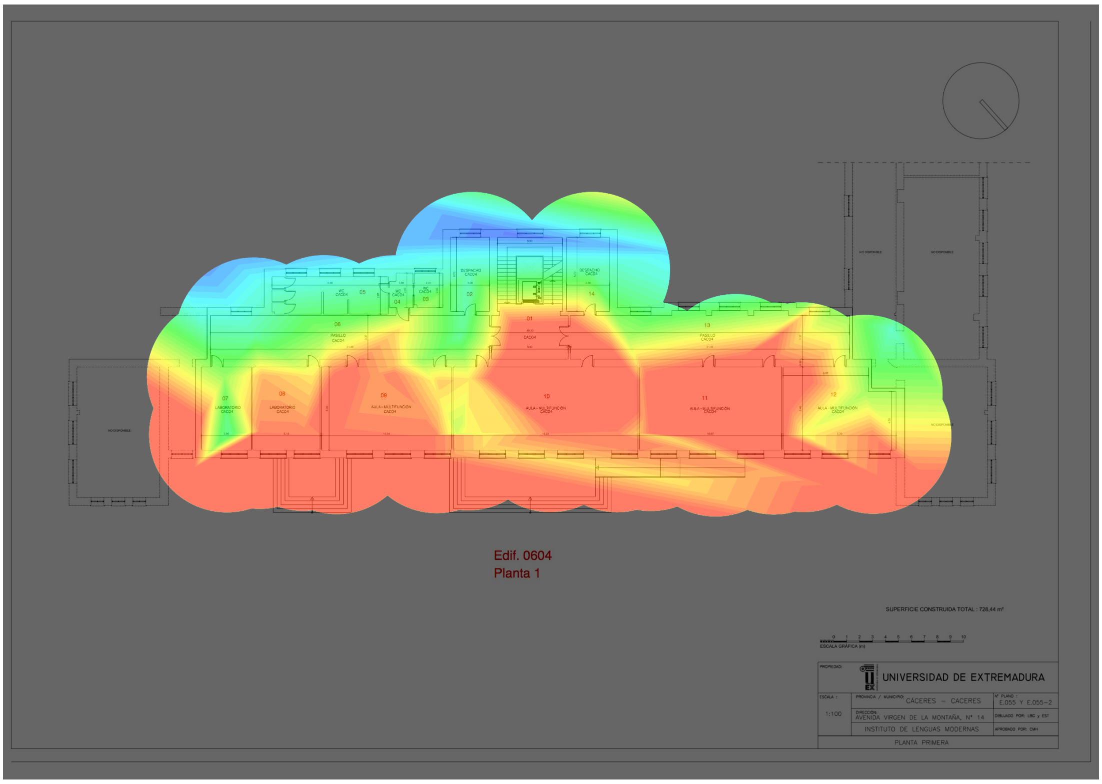


In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

4.9.2. Building 0604 Floor 1

4.9.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

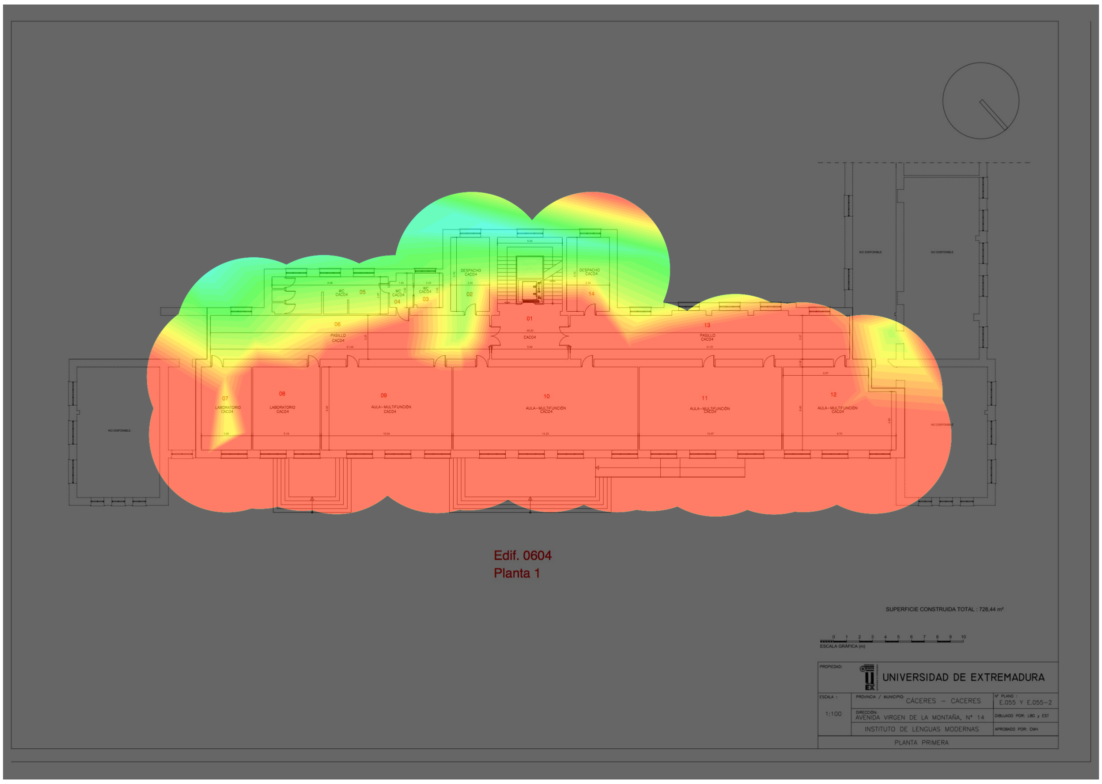


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.9.2.2. Signal Level



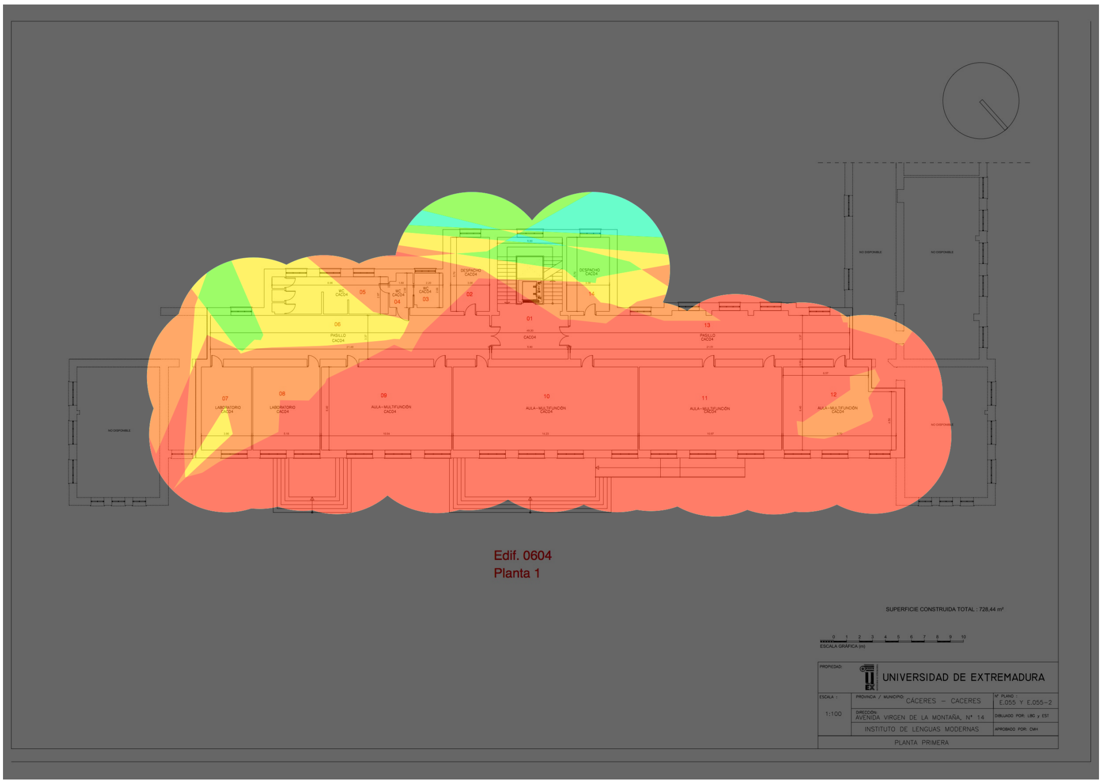
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.9.2.3. Number of Access Points

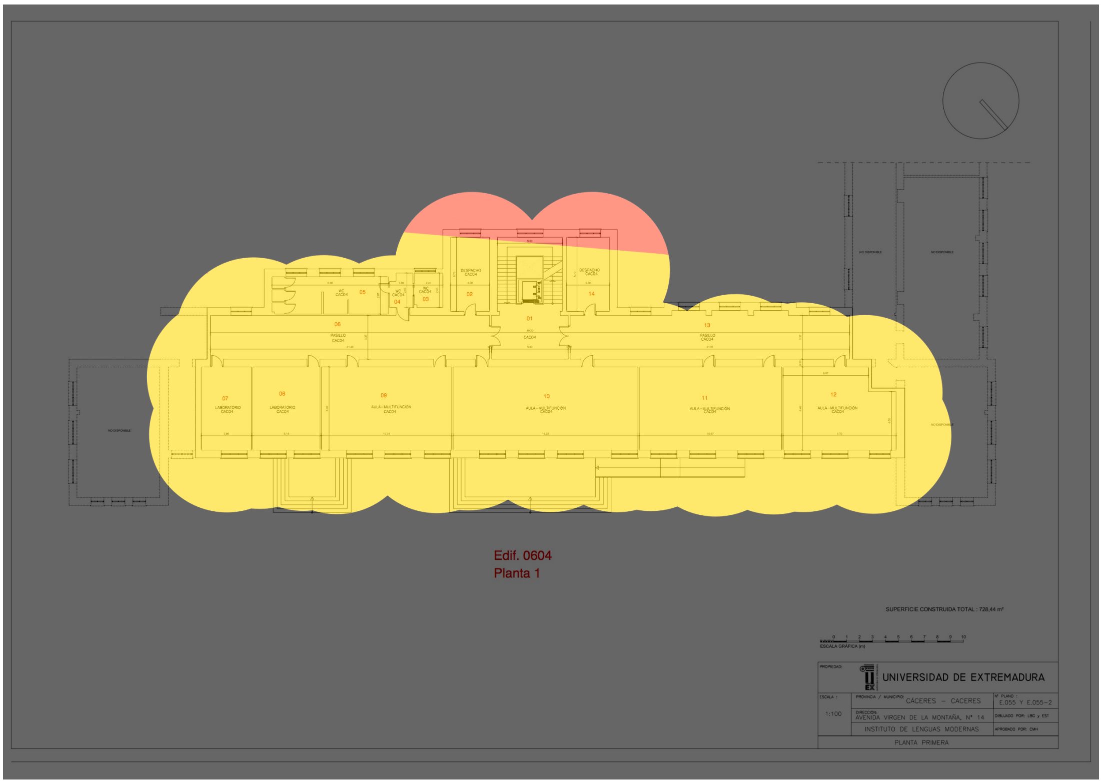


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.9.2.4. Coverage per Frequency Band

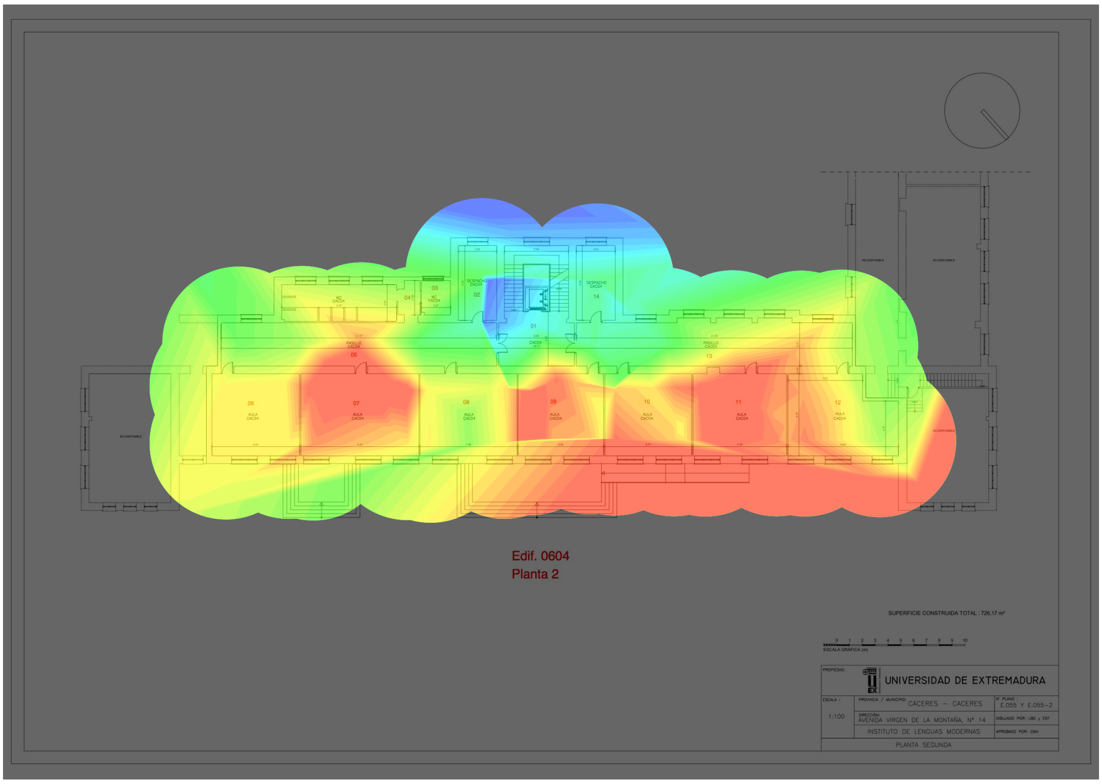


In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

4.9.3. Building 0604 Floor 2

4.9.3.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

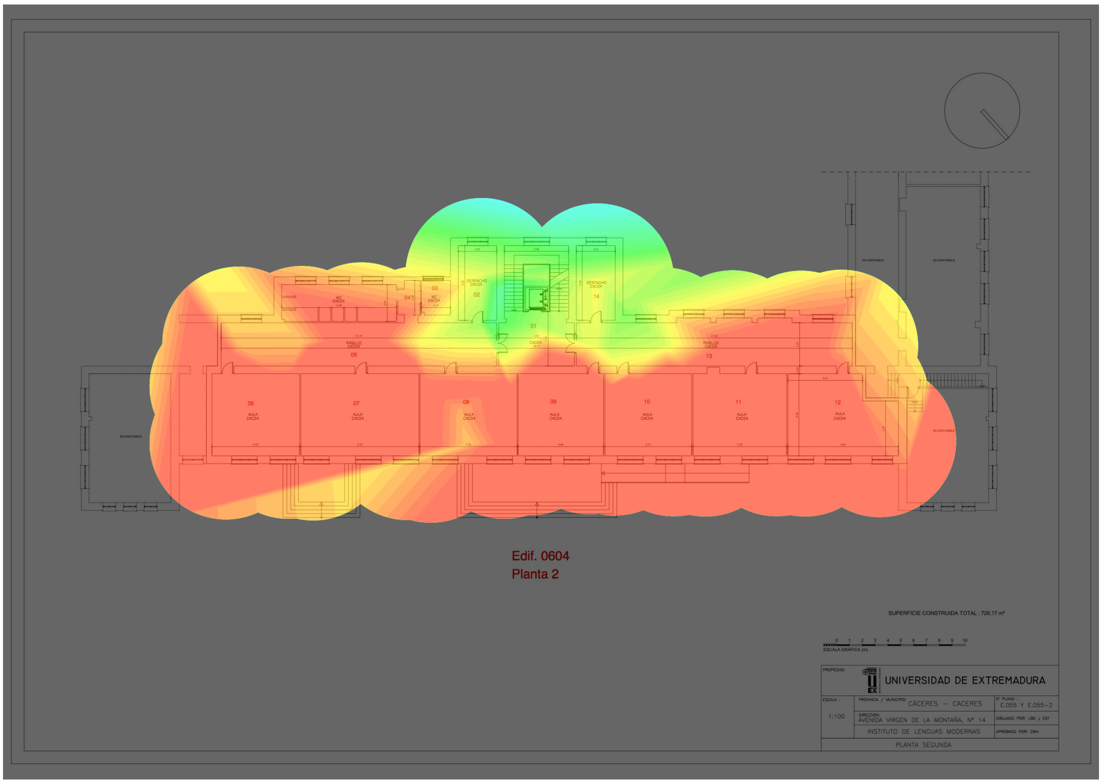


It can be seen that the areas where the classrooms are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.9.3.2. Signal Level



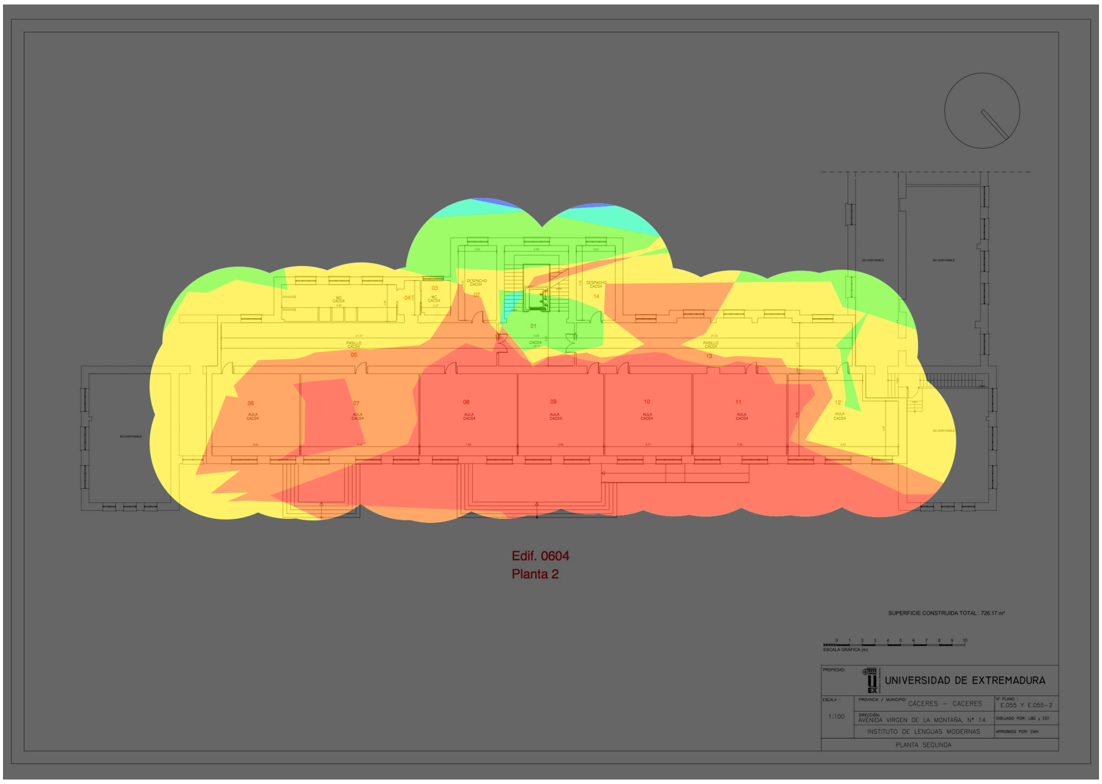
In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.9.3.3. Number of Access Points

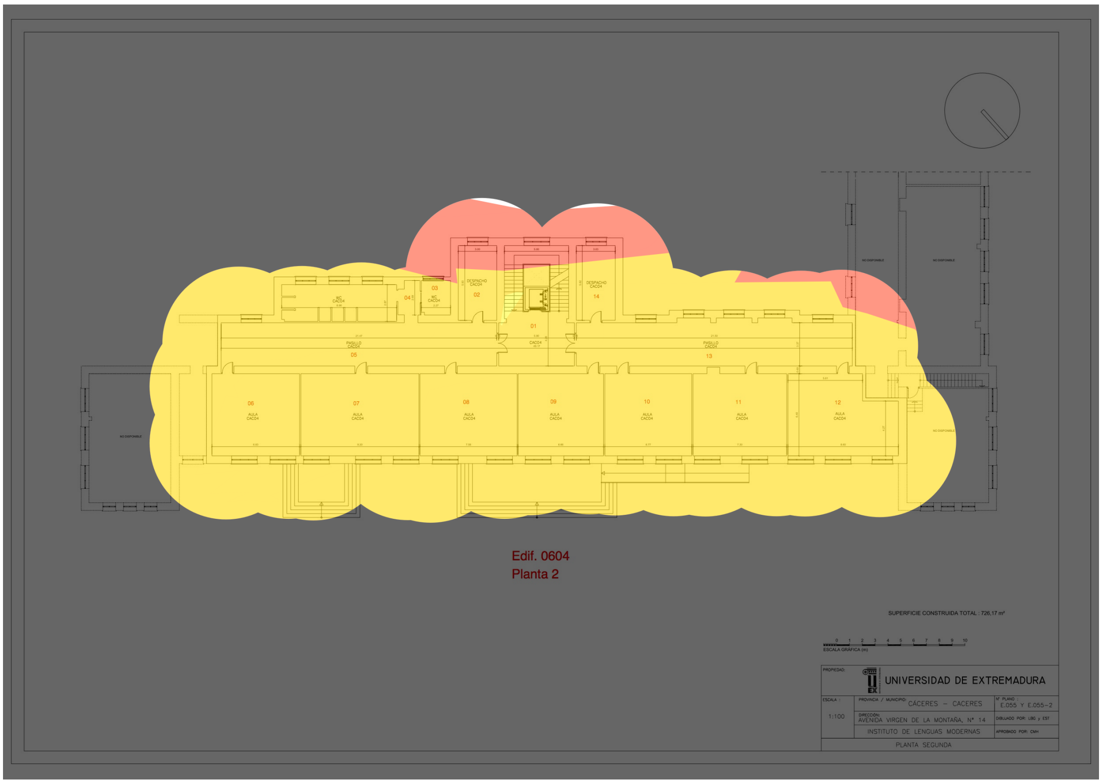


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.9.4.4. Coverage per Frequency Band

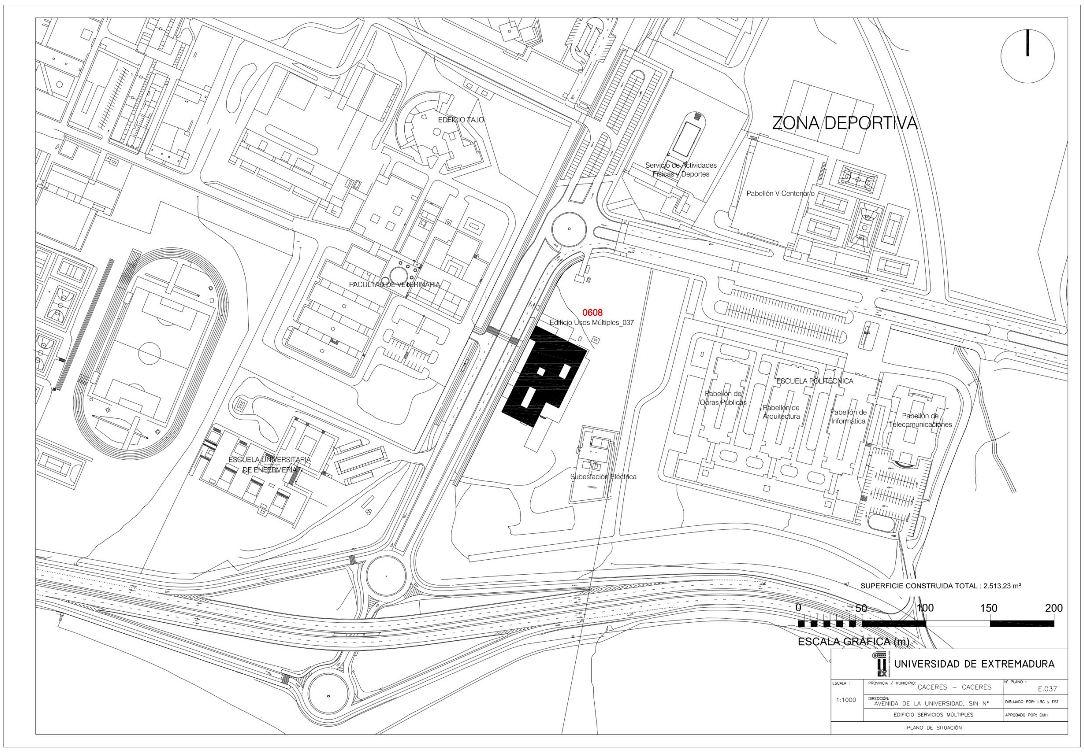


In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

4.10. Edificio de Usos Múltiples

A total of 84 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

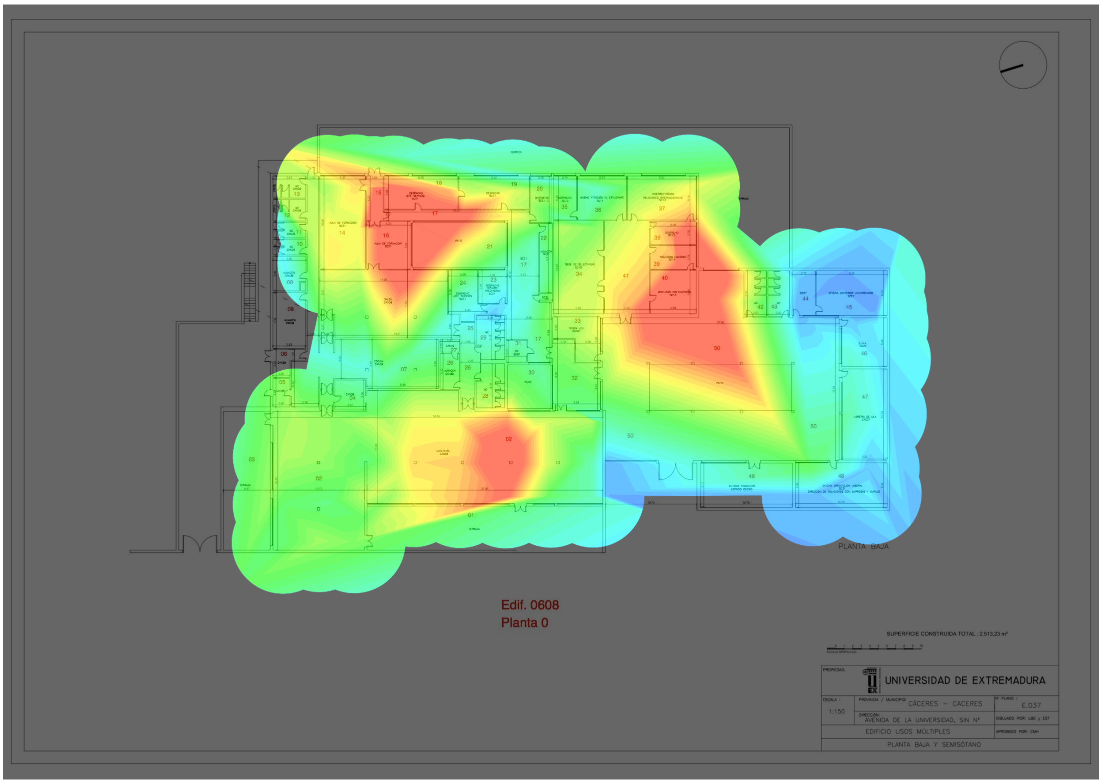
We see the location of the building on the following plan.



4.10.1. Building 0608 Floor 0

4.10.1.1. Signal to Noise Ratio

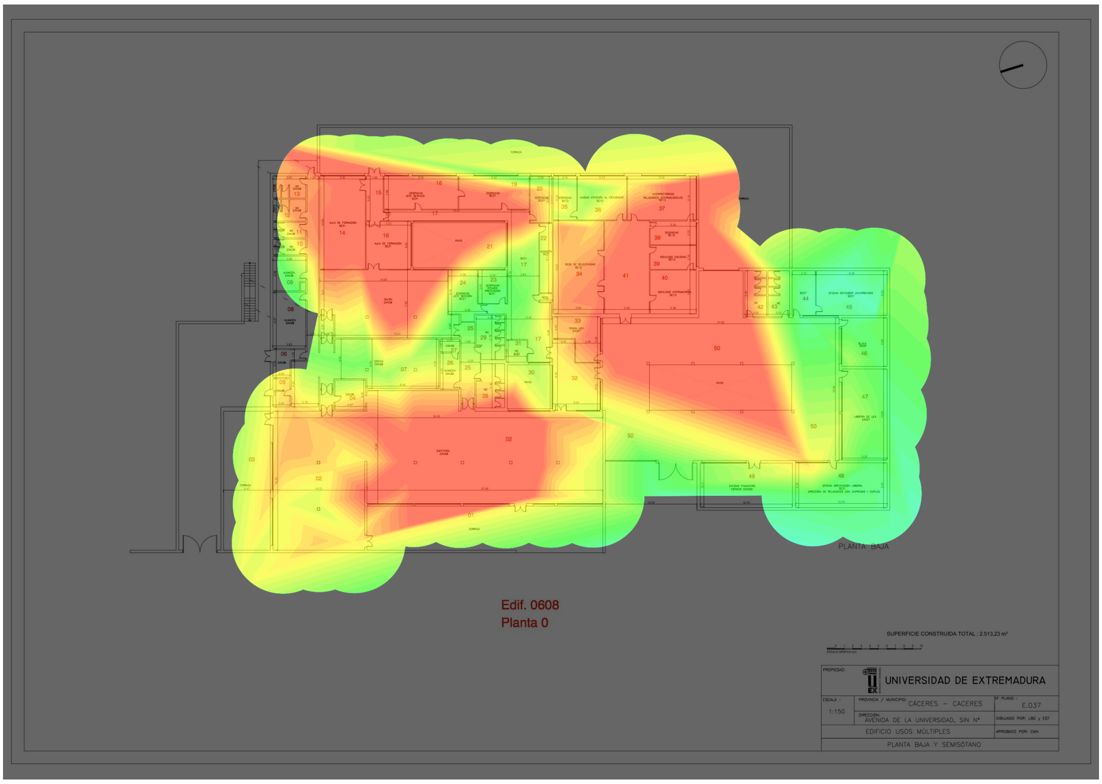
In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.



The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.10.1.2. Signal Level



We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

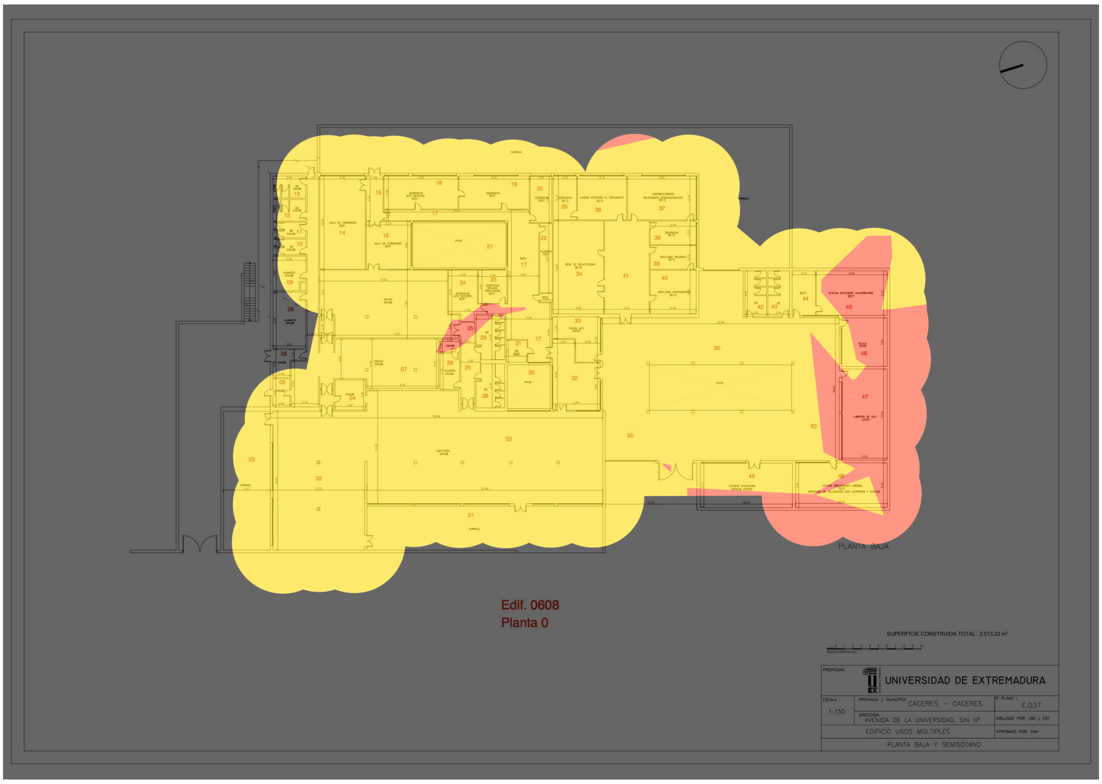
- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.10.1.3. Number of Access Points

In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.10.1.4. Coverage per Frequency Band



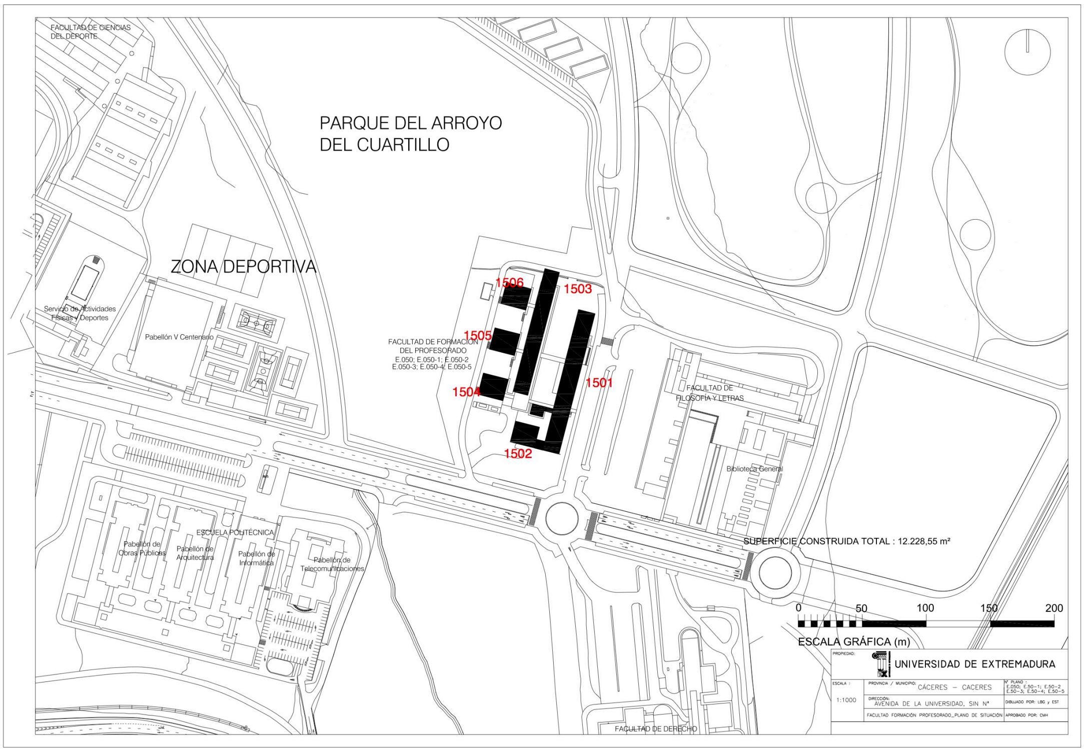
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.11. Facultad de Formación del Profesorado

A total of 343 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

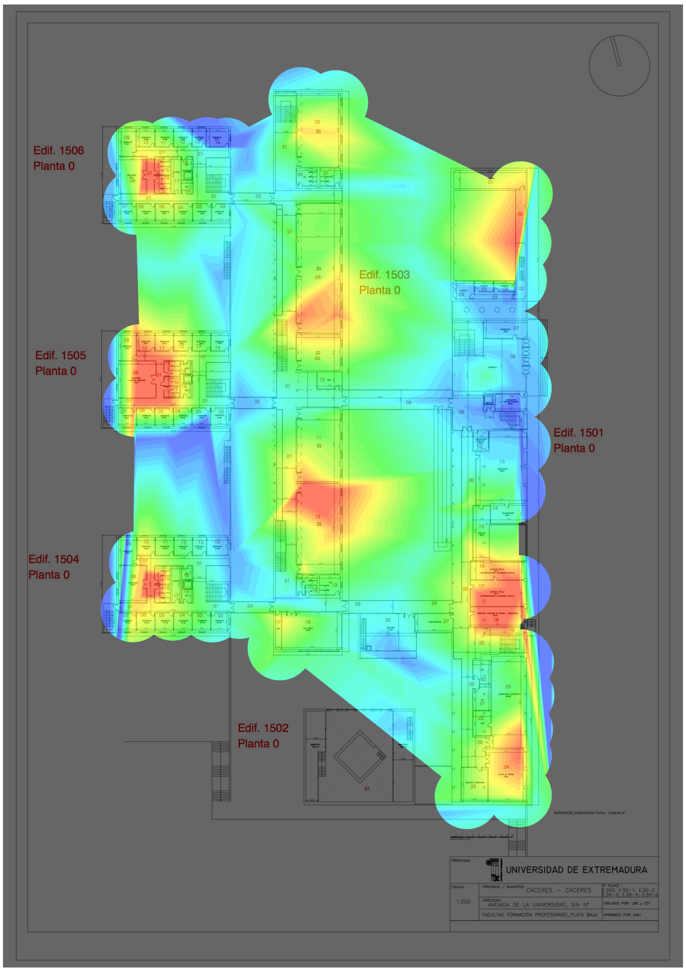
We see the location of the faculty on the following plan.



4.11.1. Building 1501-1506 Floor 0

4.11.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

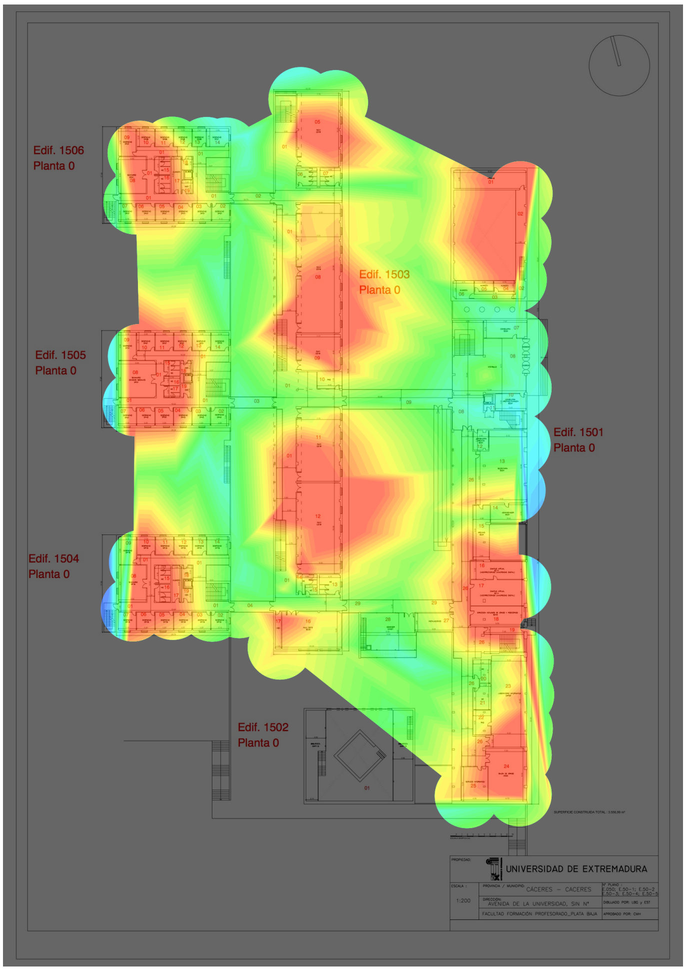


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.11.1.2. Signal Level



In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

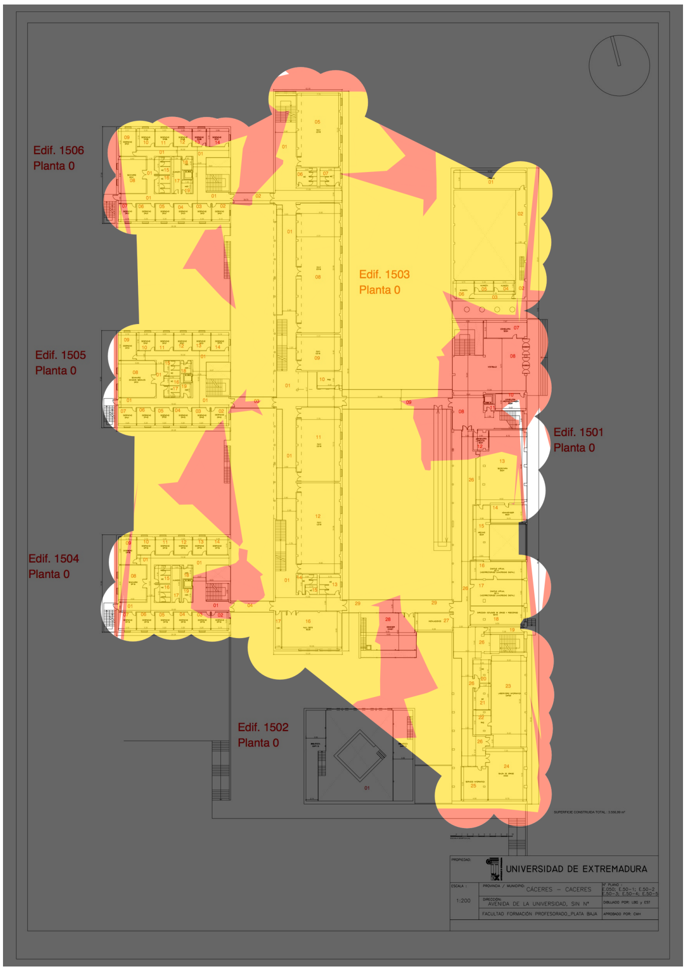
4.11.1.3. Number of Access Points

In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.11.1.4. Coverage per Frequency Band



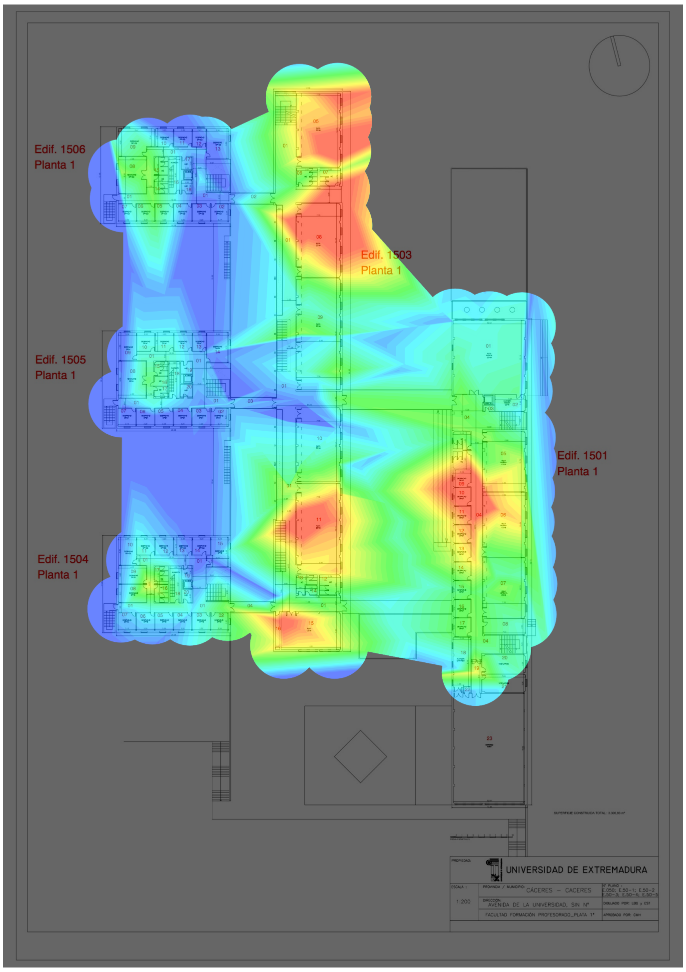
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.11.2. Building 1501-1506 Floor 1

4.11.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

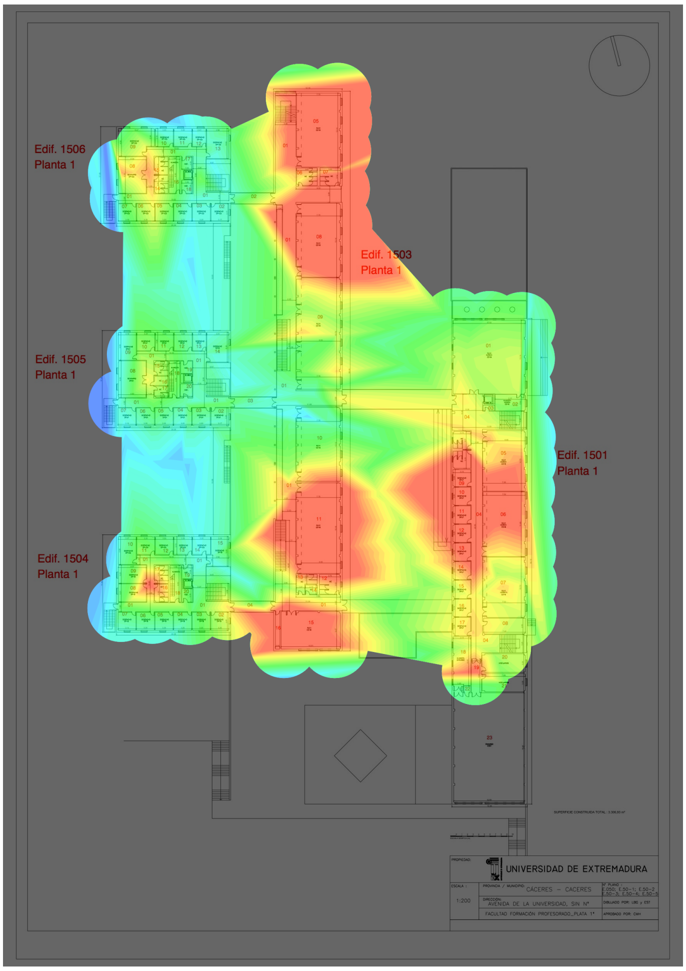


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.11.2.2. Signal Level



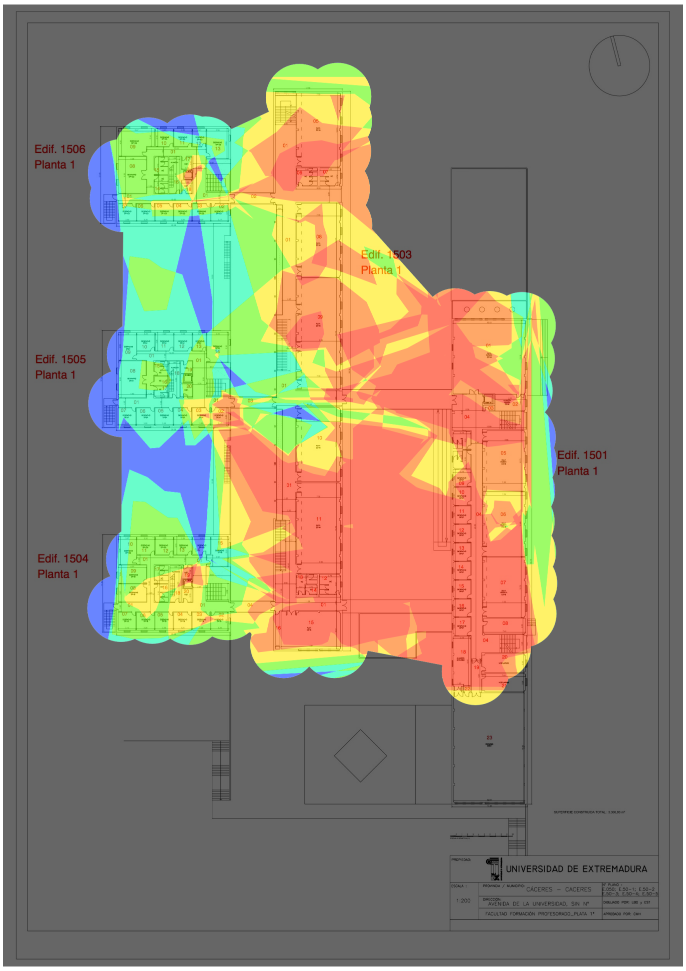
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.11.2.3. Number of Access Points

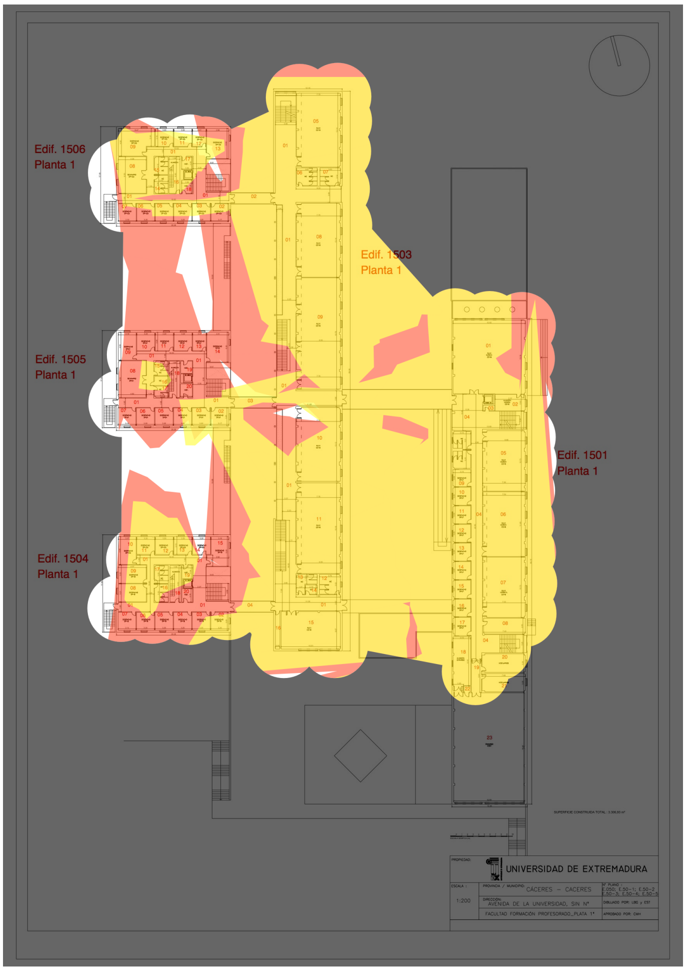


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.11.2.4. Coverage per Frequency Band



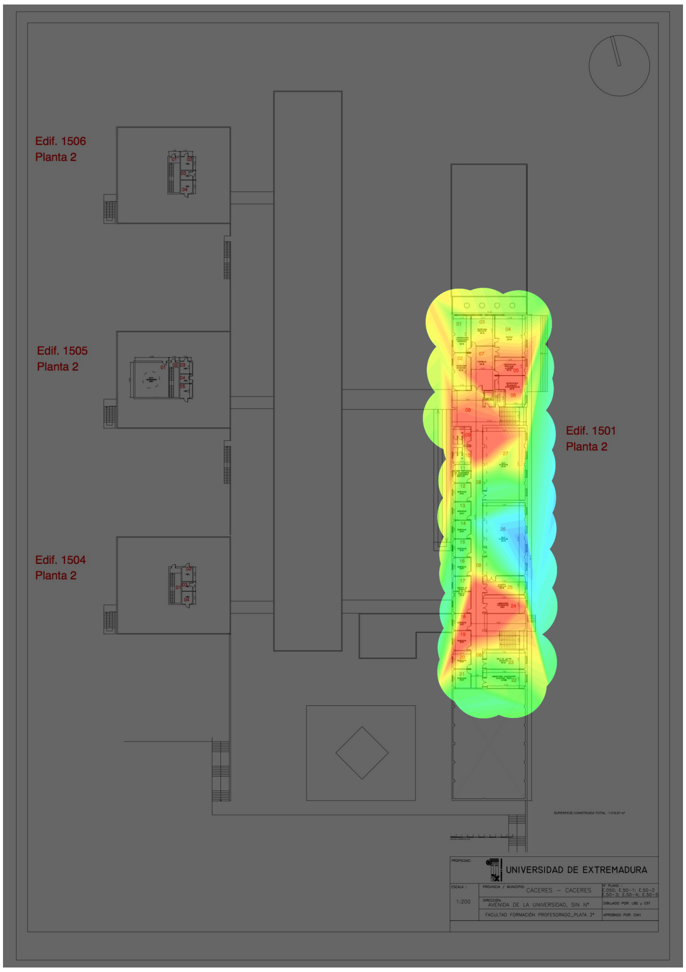
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.11.3. Building 1501-1506 Floor 2

4.11.3.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

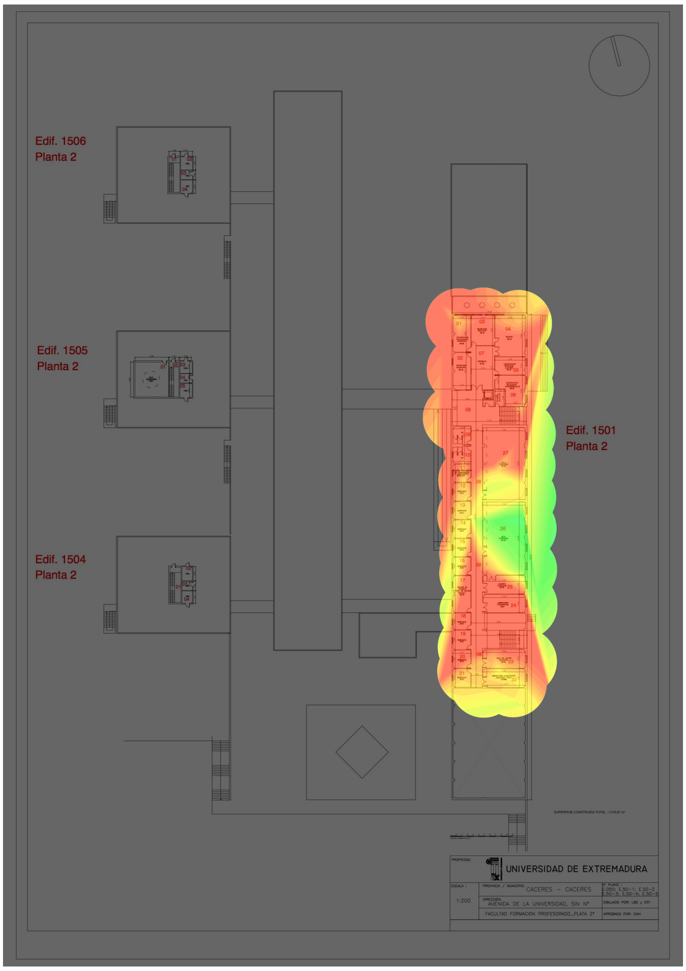


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.11.3.2. Signal Level



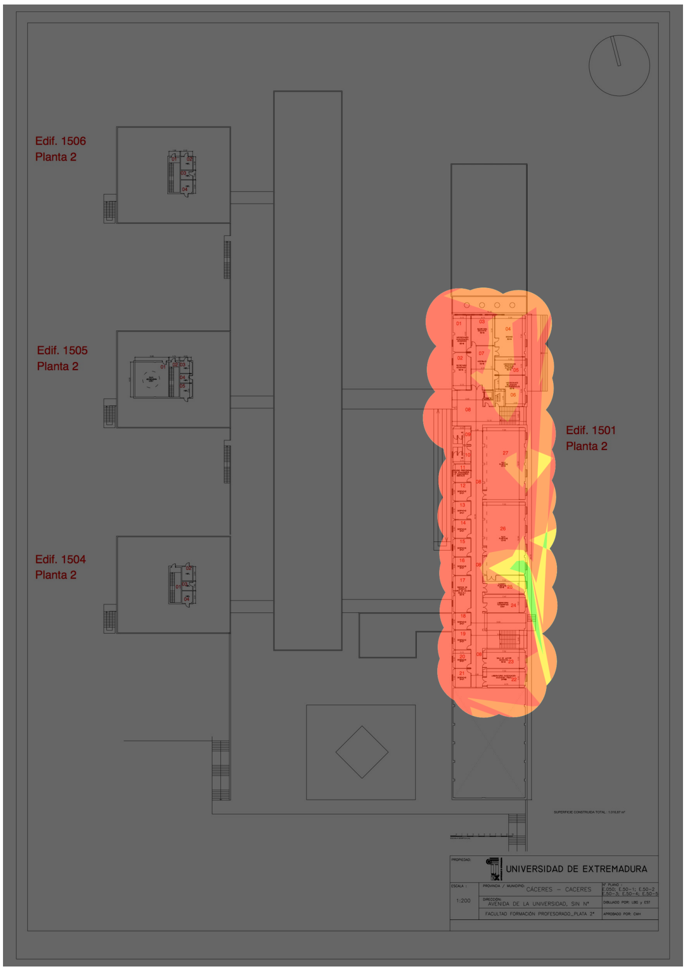
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.11.3.3. Number of Access Points

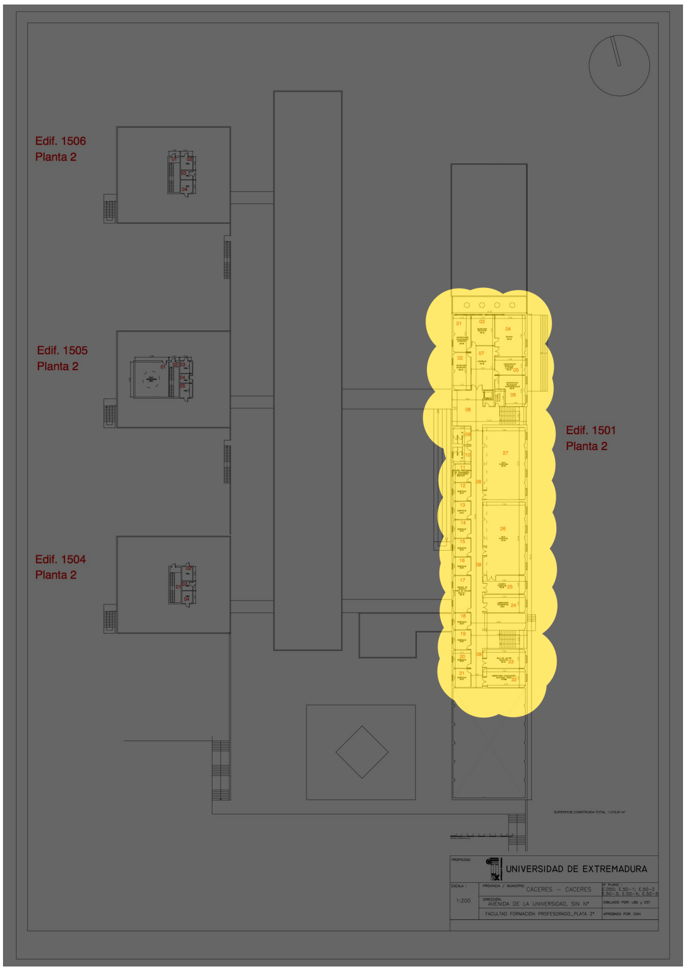


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.11.3.4. Coverage per Frequency Band

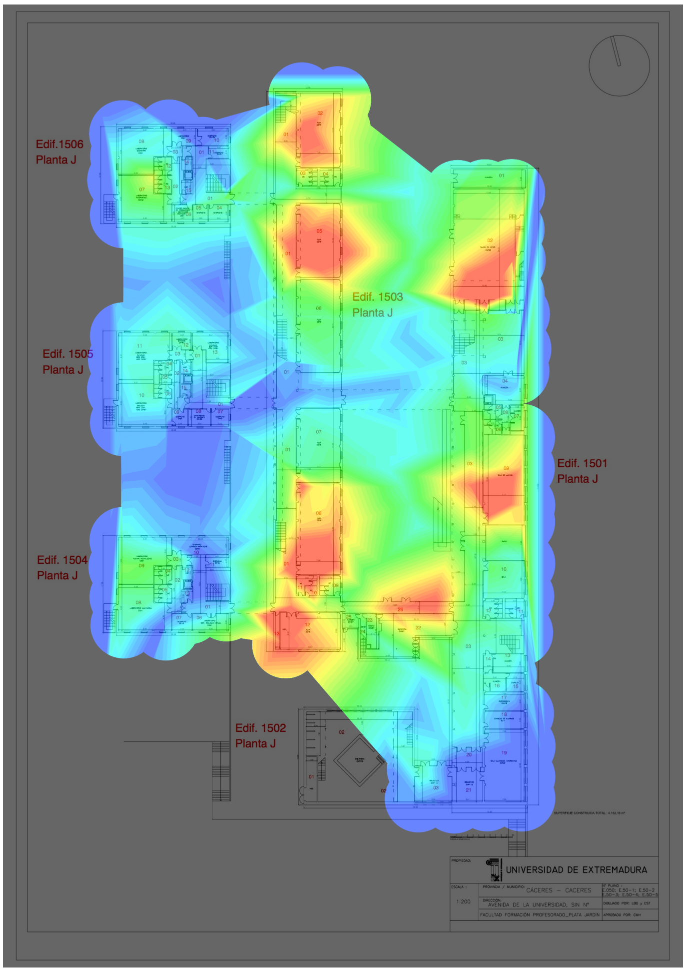


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.11.4. Building 1501-1506 Floor J

4.11.4.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

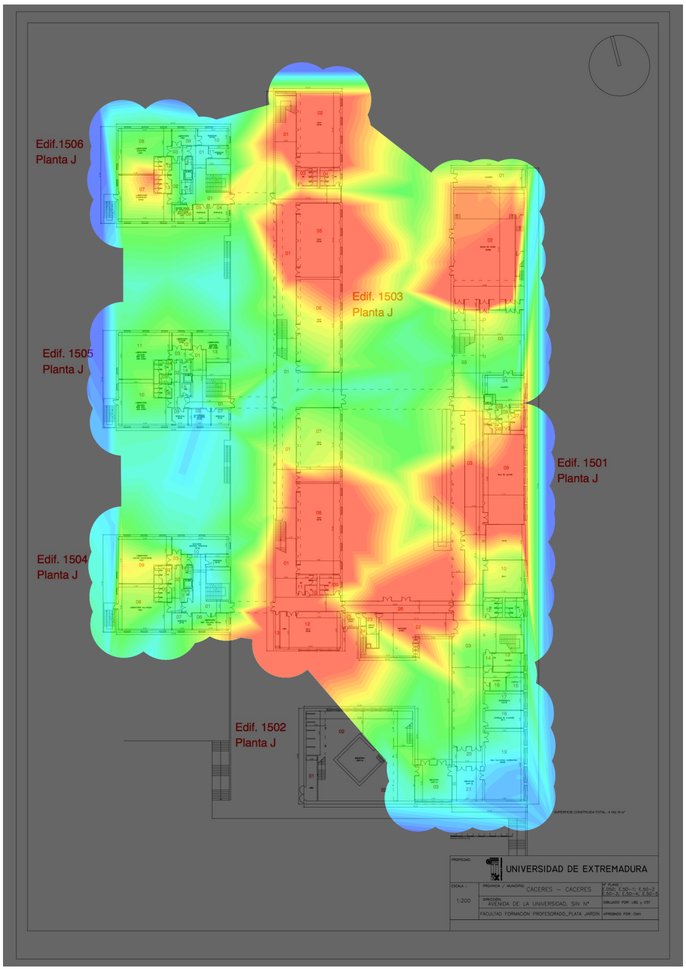


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.11.4.2. Signal Level



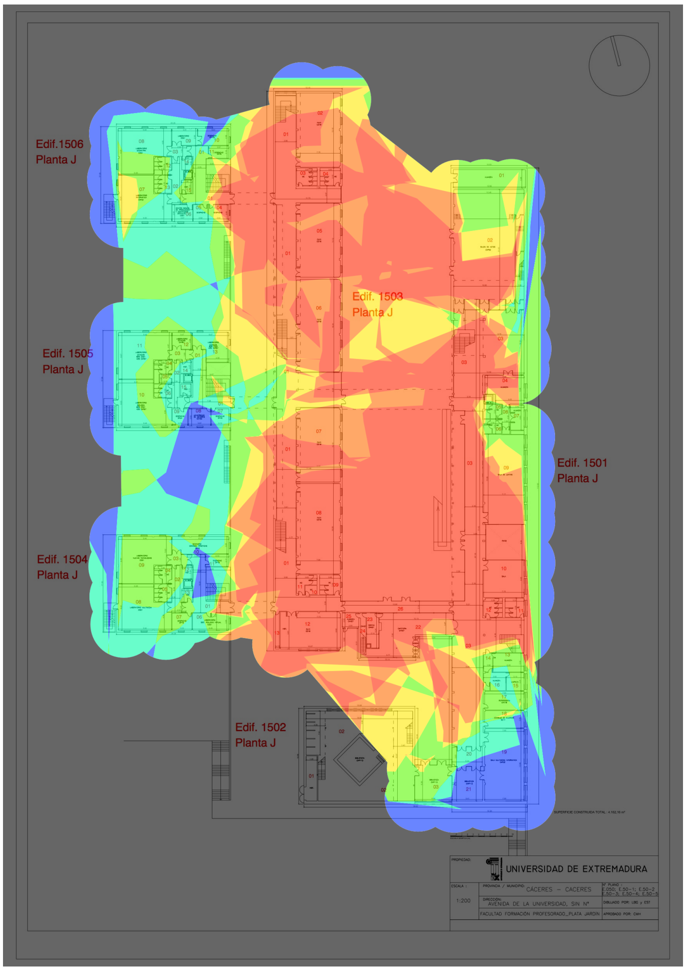
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.11.4.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.11.4.4. Coverage per Frequency Band

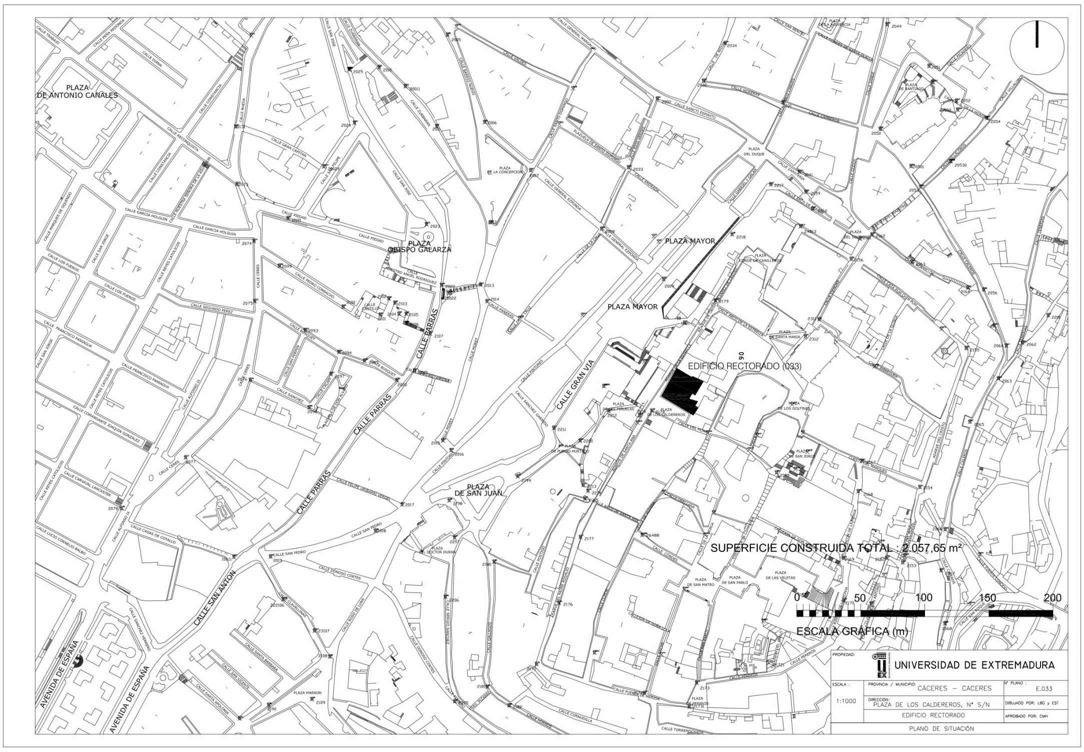
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.12. Rectorado Cáceres

A total of 90 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

We see the location of the building on the following plan.



4.12.1. Building 0601 Floor 0

4.12.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.12.1.2. Signal Level

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.12.1.3. Number of Access Points

In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.12.1.4. Coverage per Frequency Band

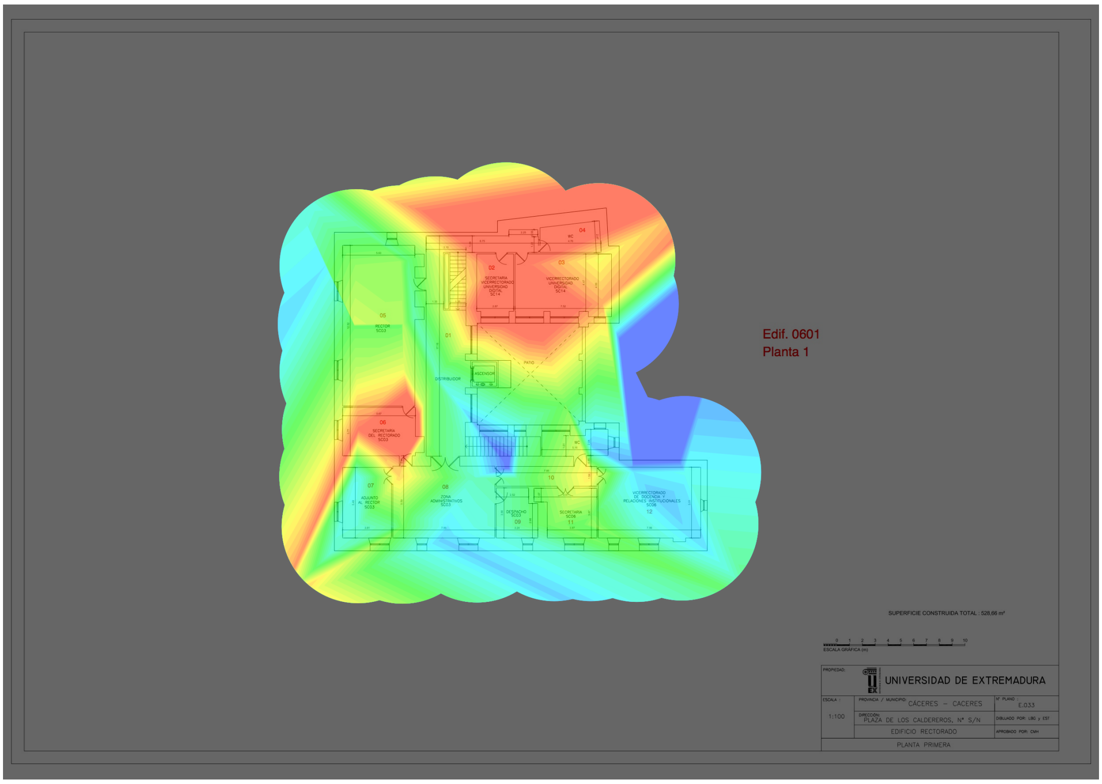
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.12.2. Building 0601 Floor 1

4.12.2.1. Signal to Noise Ratio

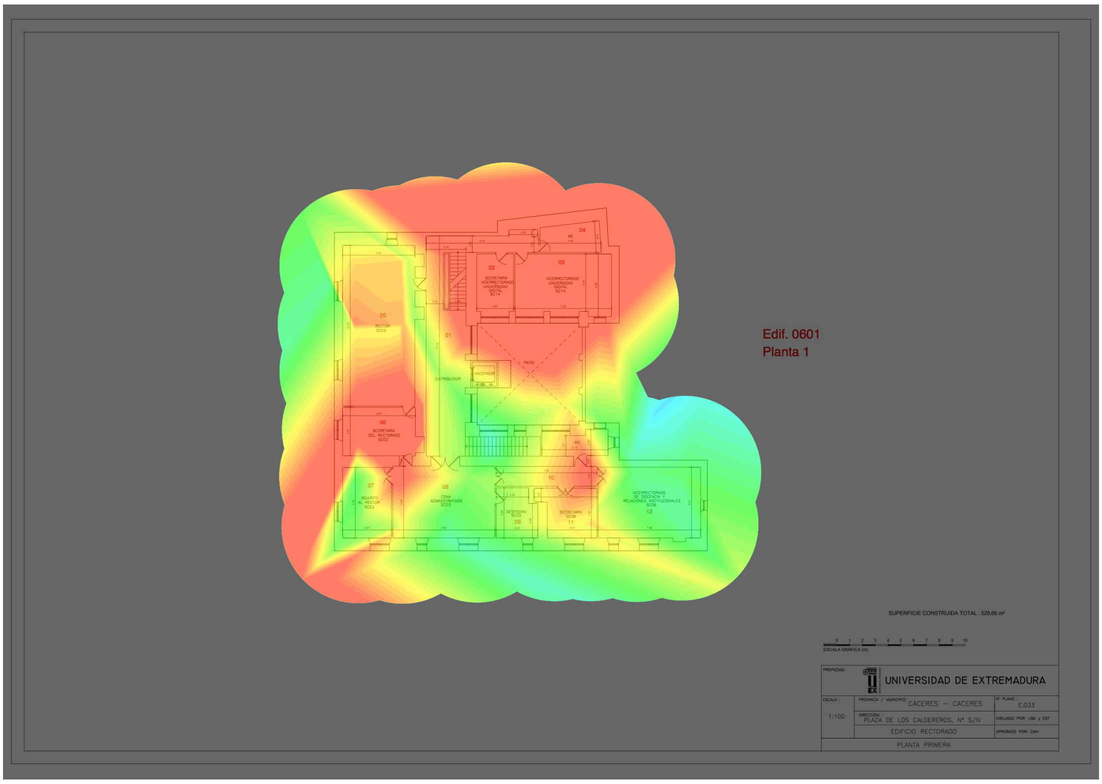
In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.



The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.12.2.2. Signal Level

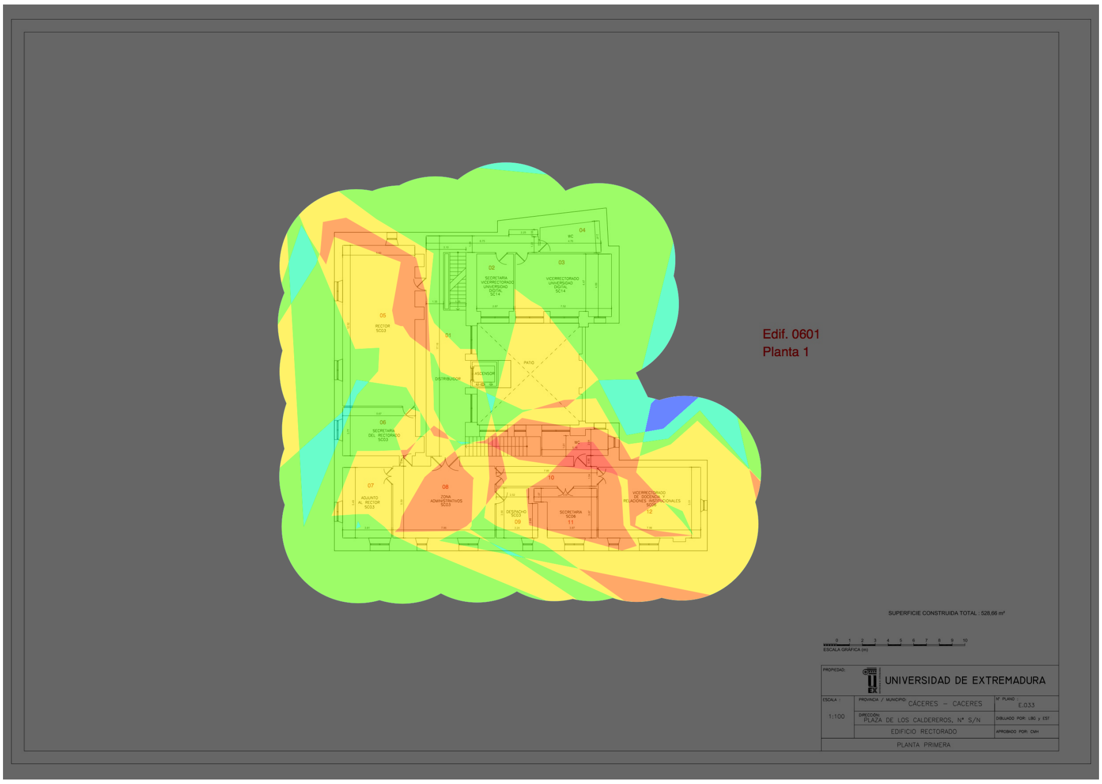


We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

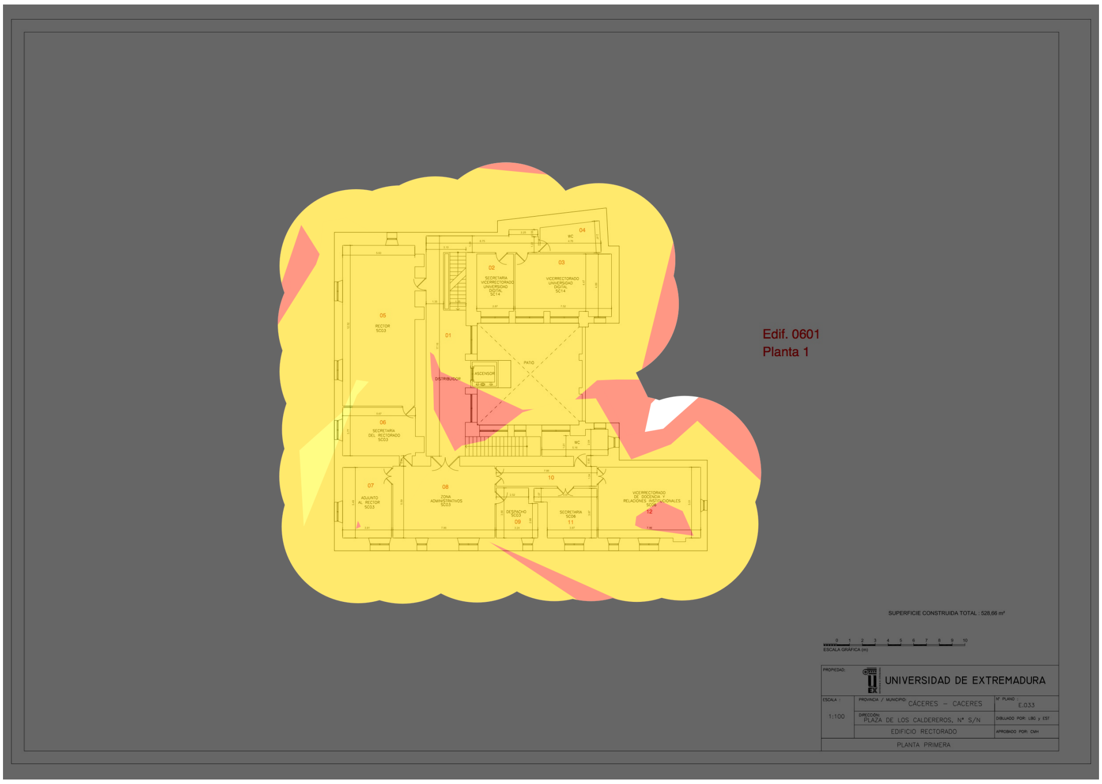
4.12.2.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.12.2.4. Coverage per Frequency Band



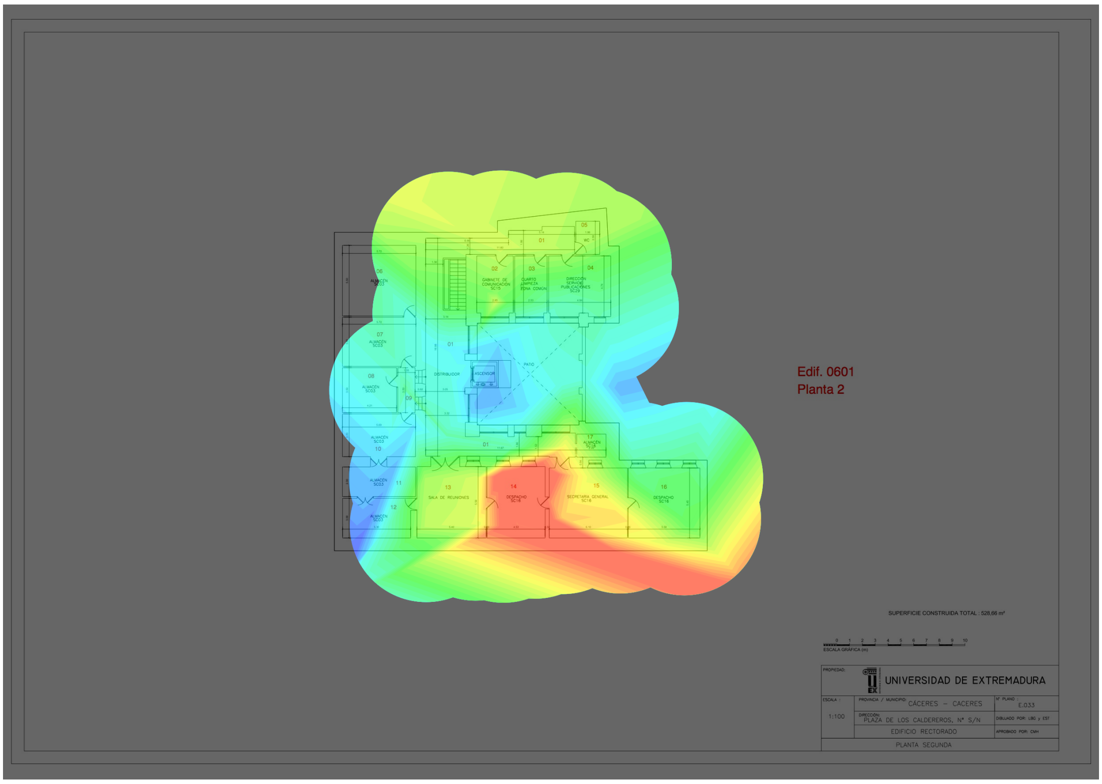
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.12.3. Building 0601 Floor 2

4.12.3.1. Signal to Noise Ratio

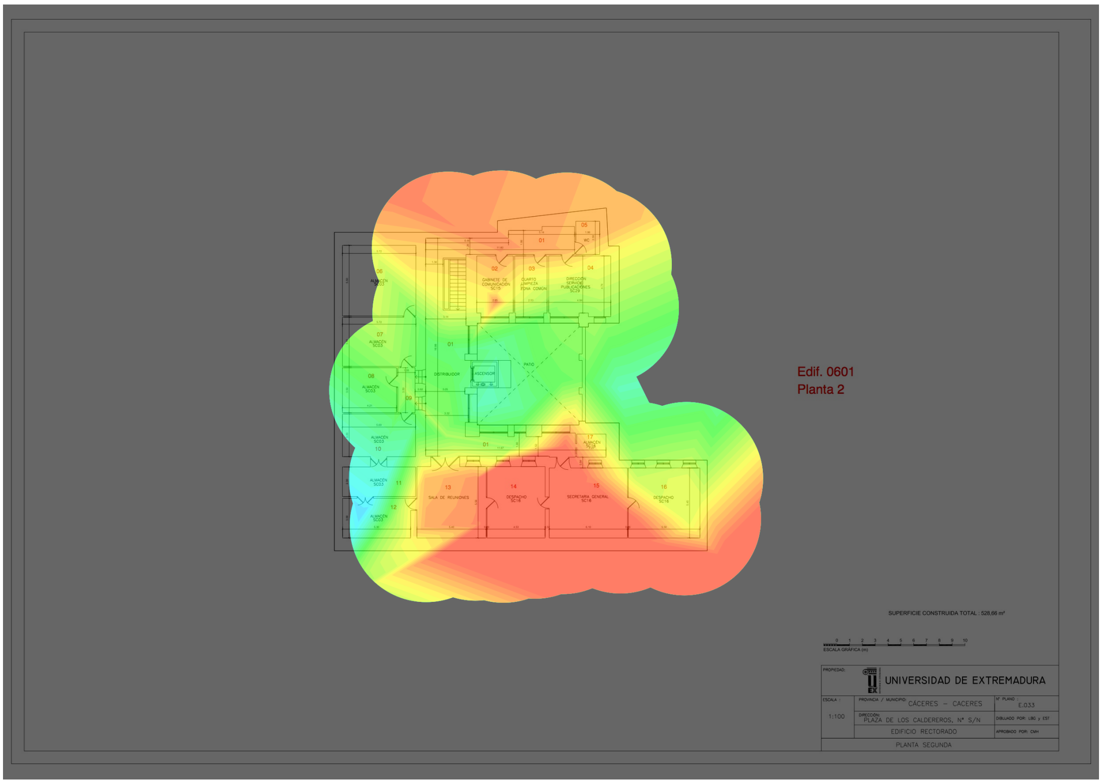
In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.



The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.12.3.2. Signal Level

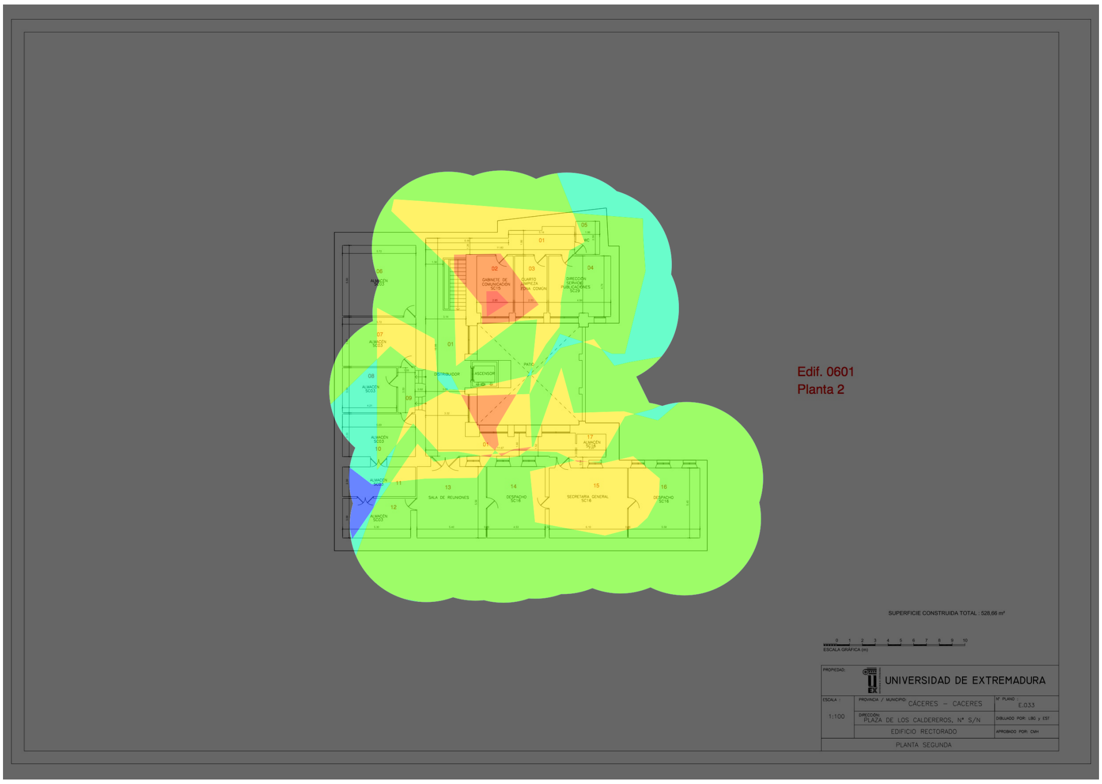


We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

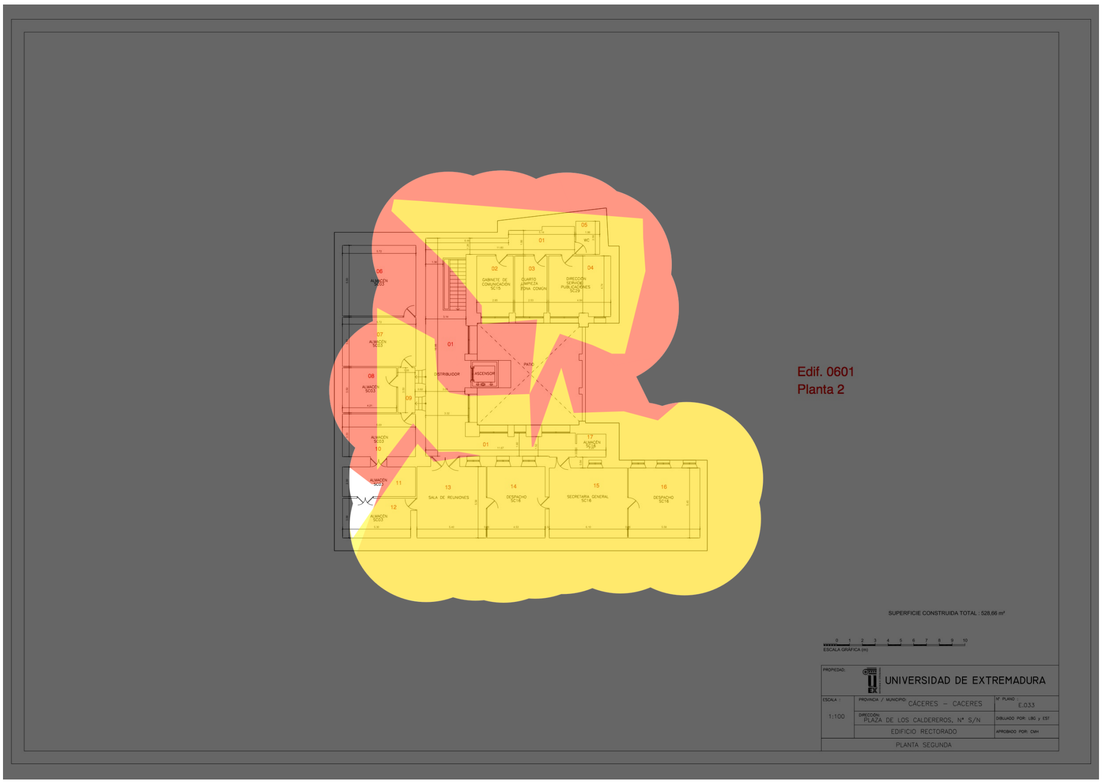
4.12.3.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.12.3.4. Coverage per Frequency Band



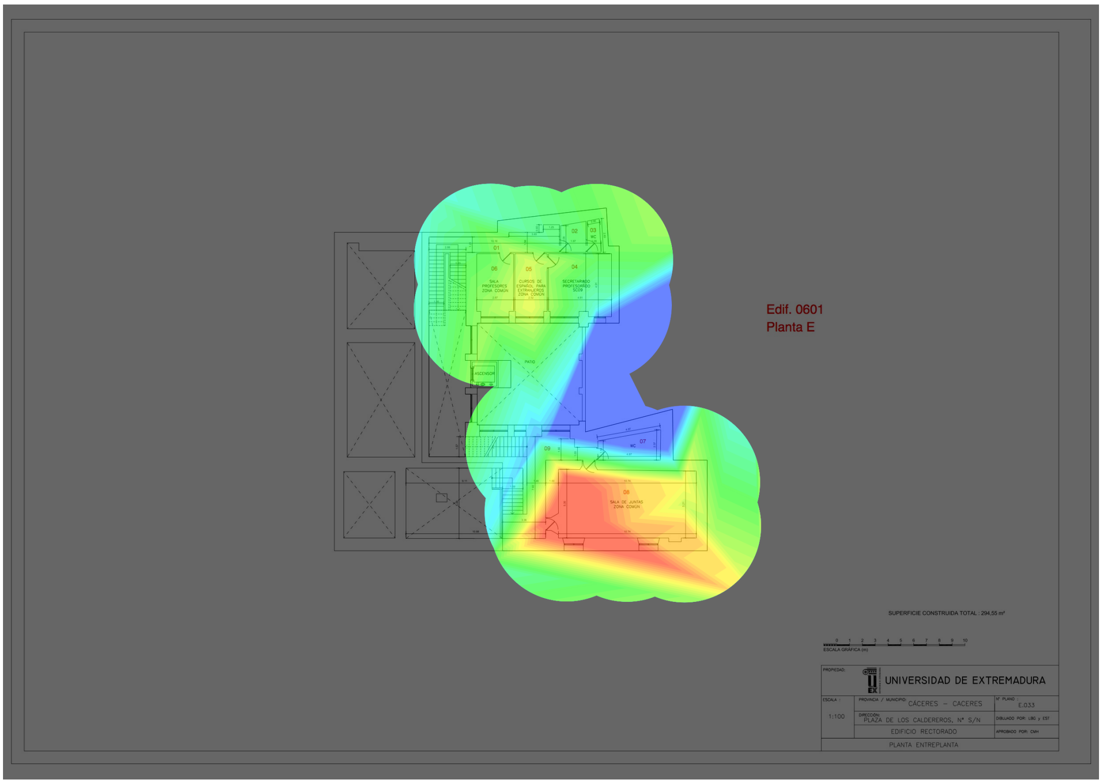
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.12.4. Building 0601 Floor E

4.12.4.1. Signal to Noise Ratio

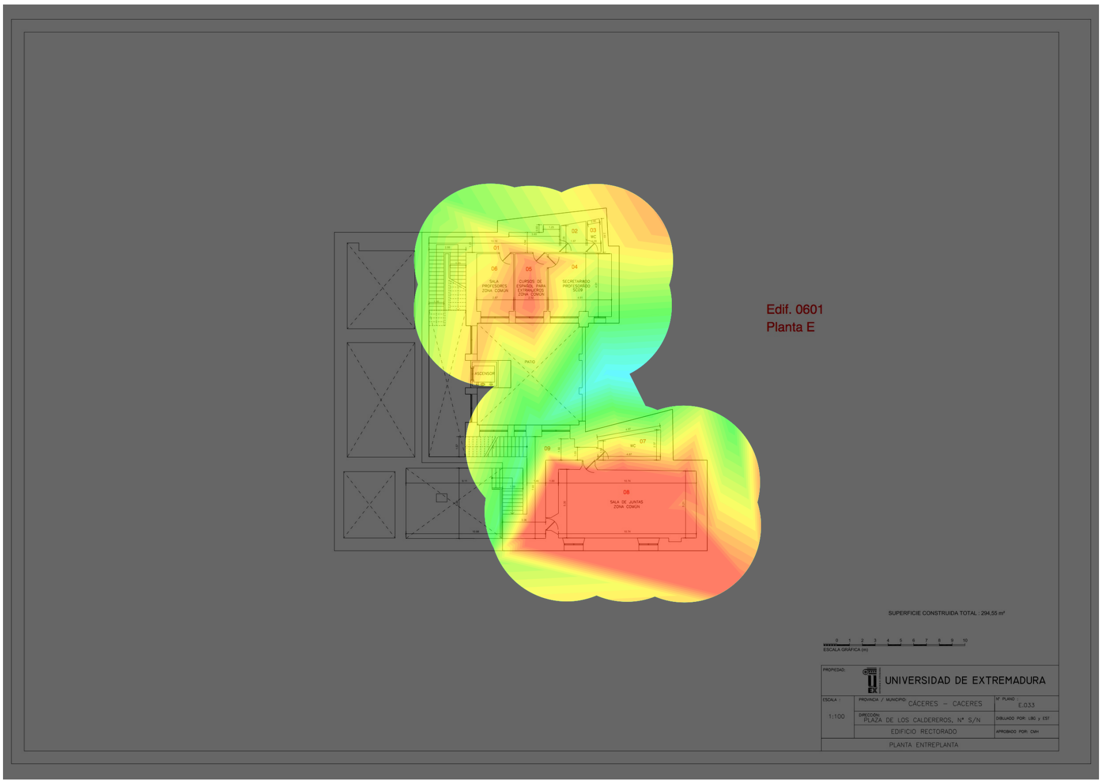
In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.



The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.12.4.2. Signal Level

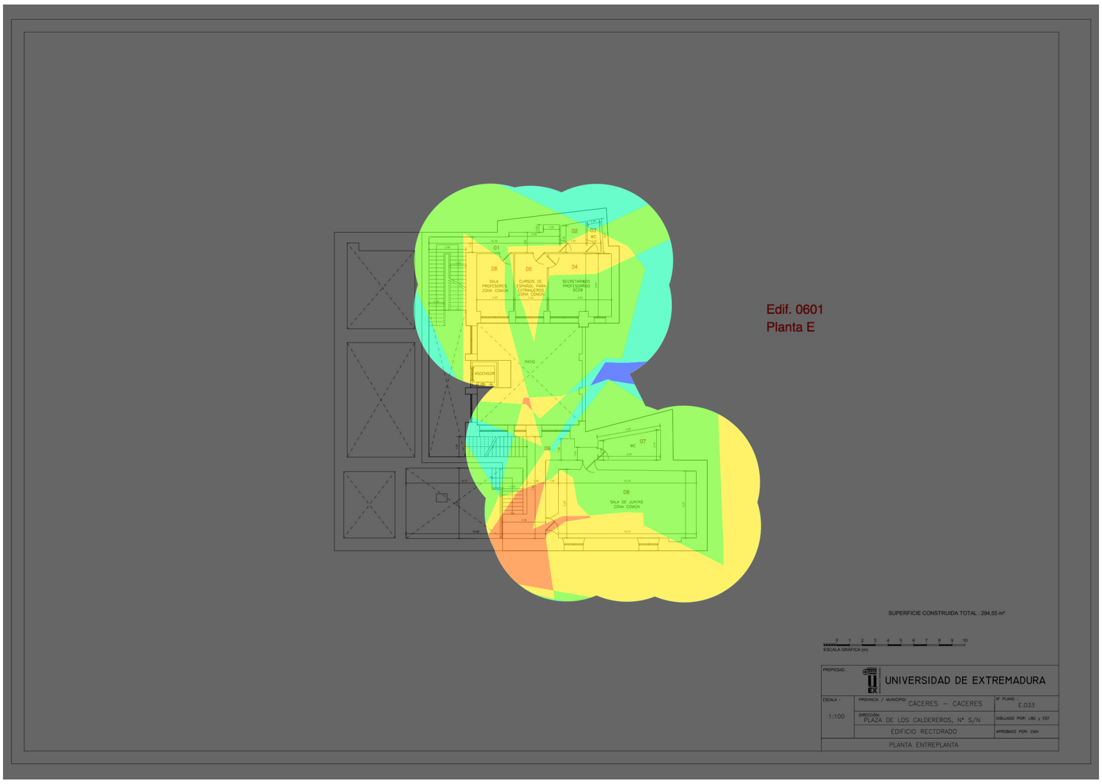


We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

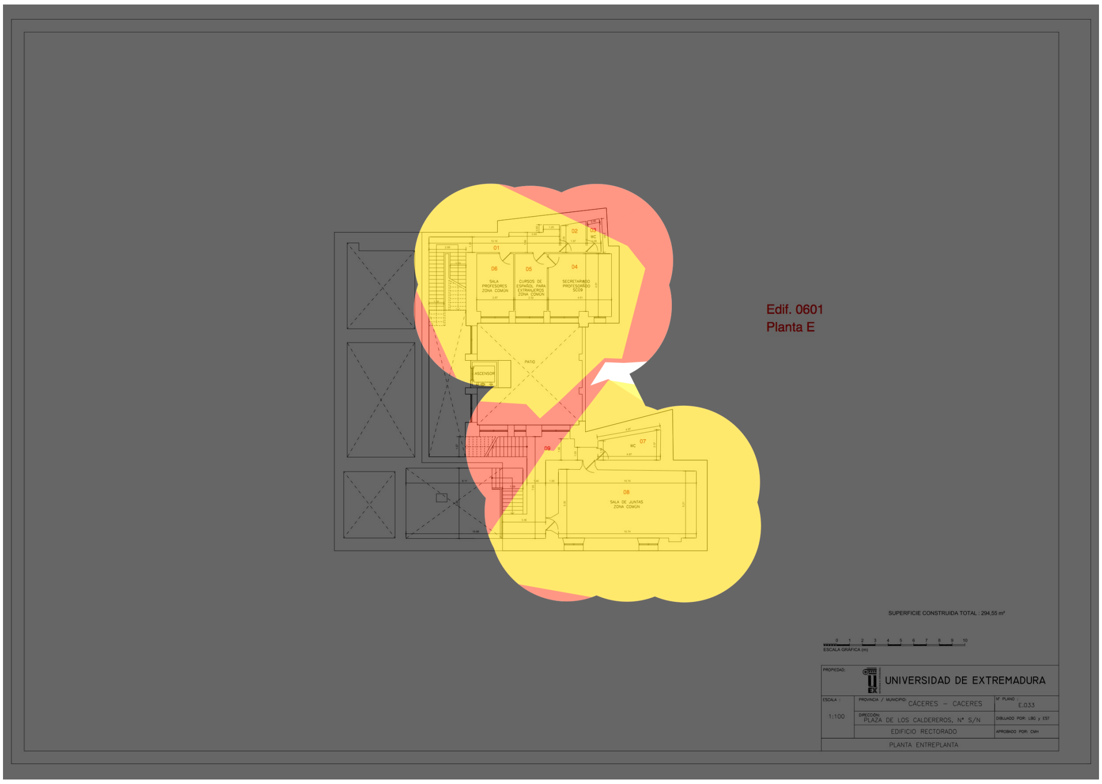
4.12.4.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.12.4.4. Coverage per Frequency Band



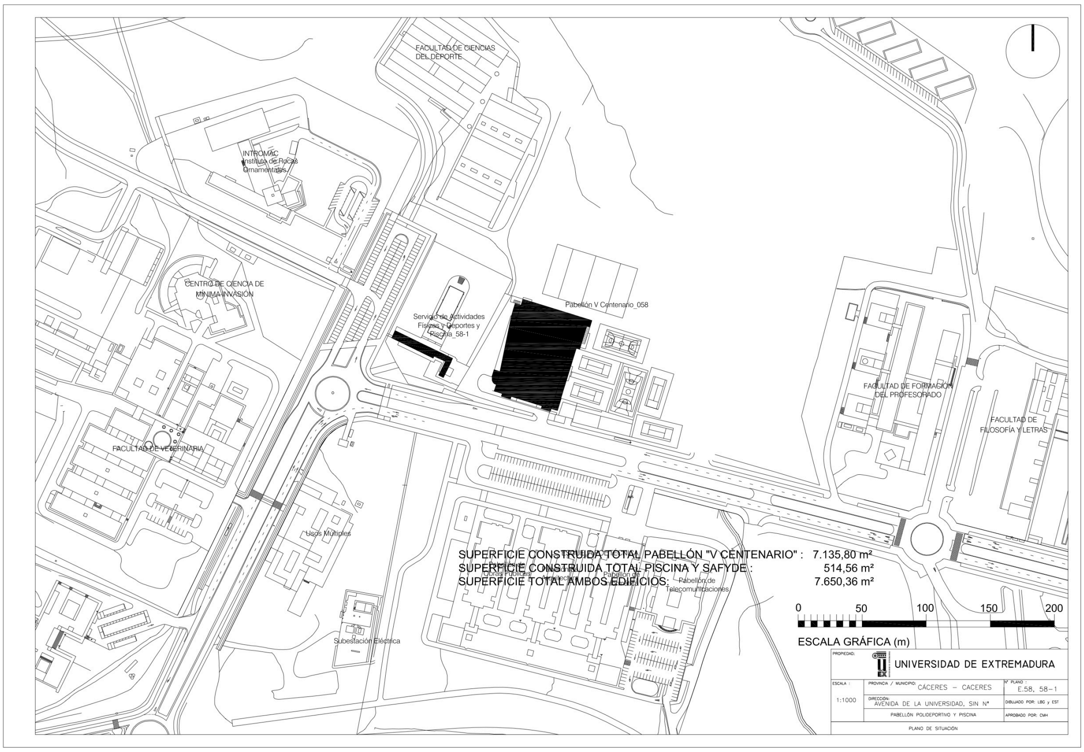
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.13. Servicio de Actividad Física y Deporte

A total of 17 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

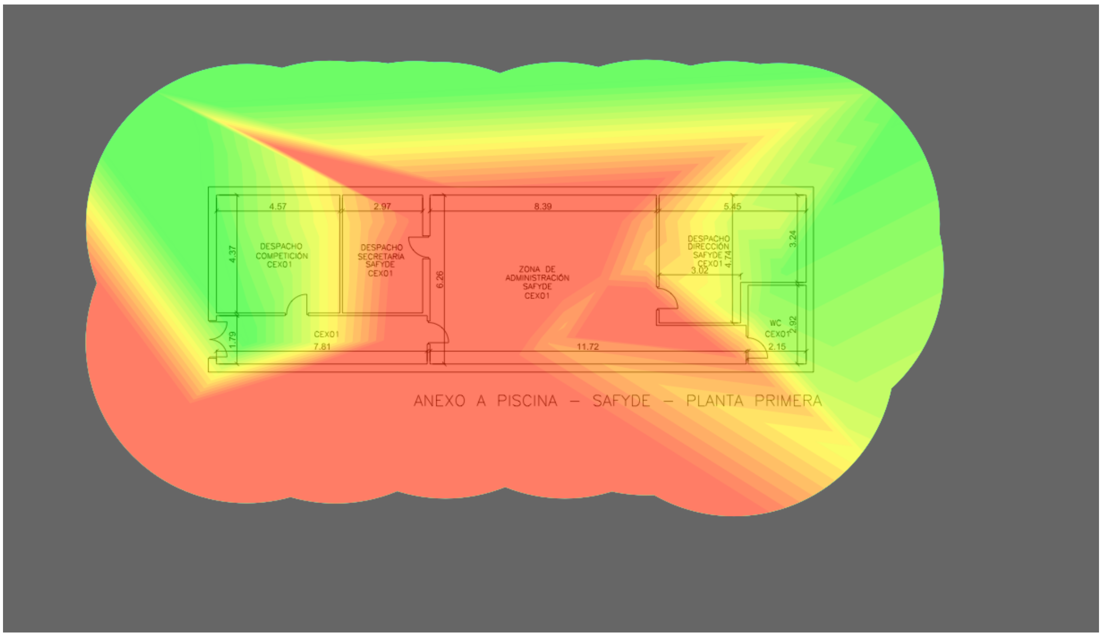
We see the location of the building on the following plan.



4.13.1. Building Anexa to Pool Floor 0

4.13.1.1. Signal to Noise Ratio

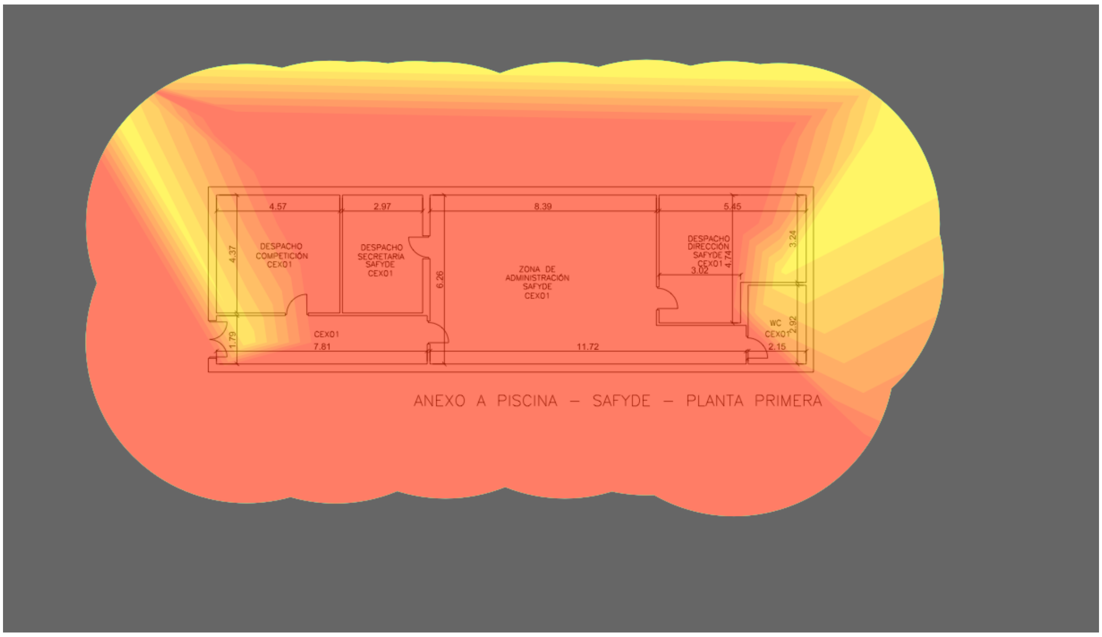
In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.



The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.13.1.2. Signal Level

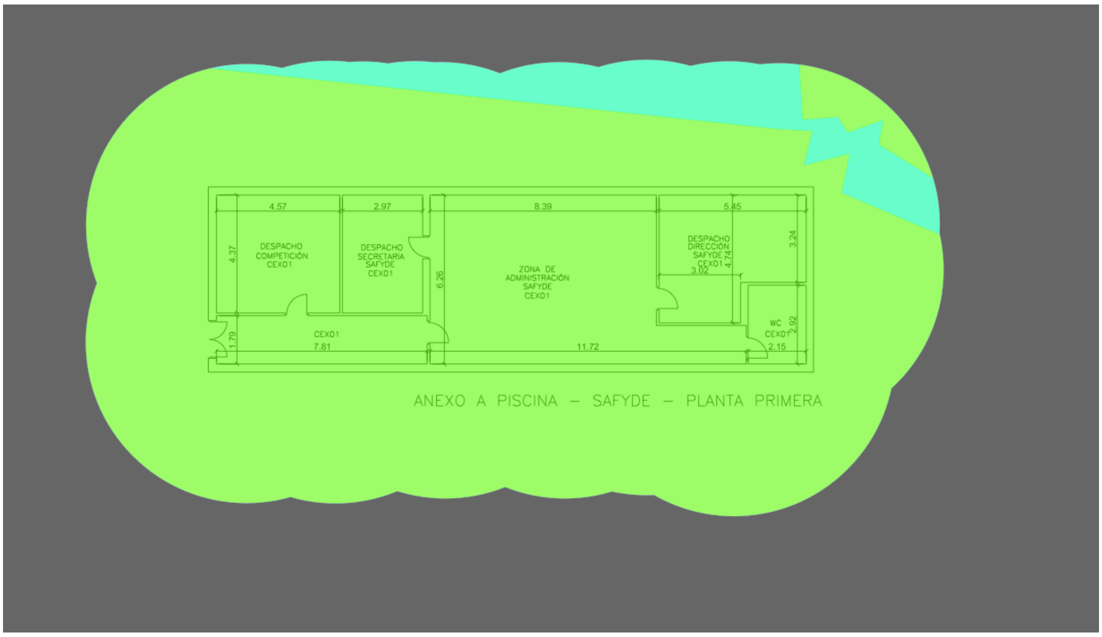


We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

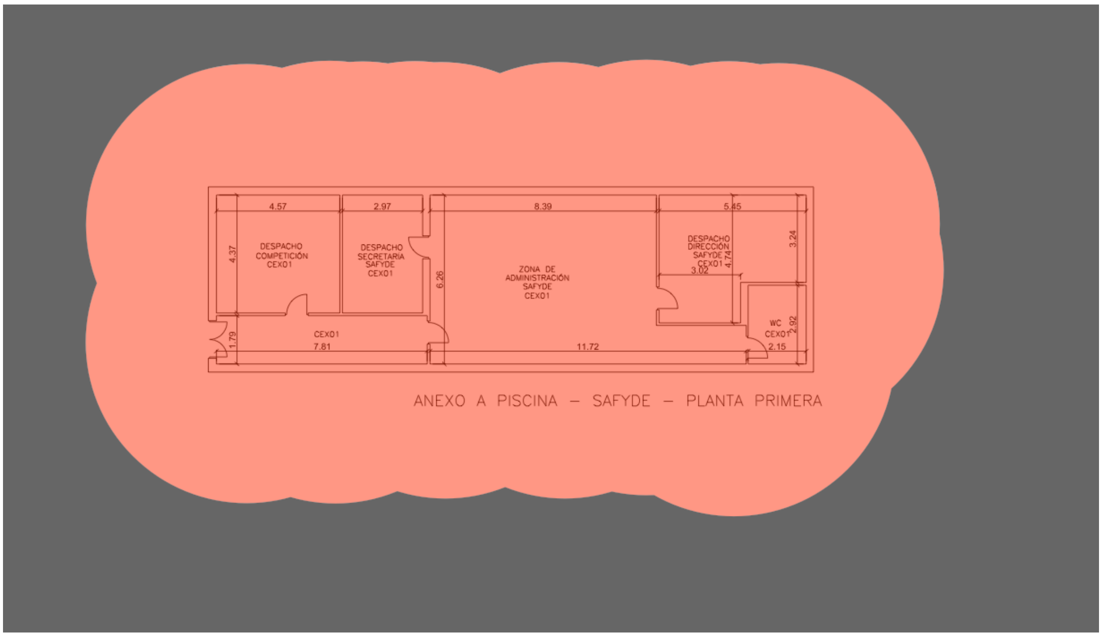
4.13.1.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.13.1.4. Coverage per Frequency Band

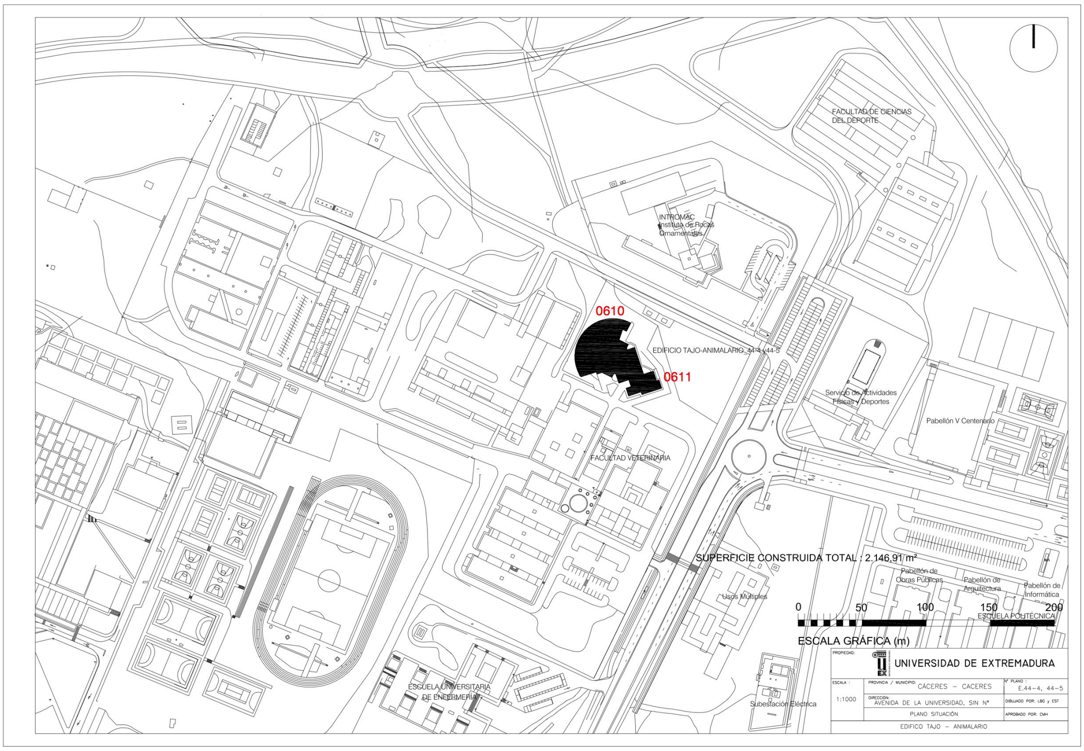


In the illustration we can see that only available the coverage in the case of 2.4 GHz.

4.14. Servicio de Gestión y Transferencia de Resultados de la Investigación (SGTRI)

A total of 38 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

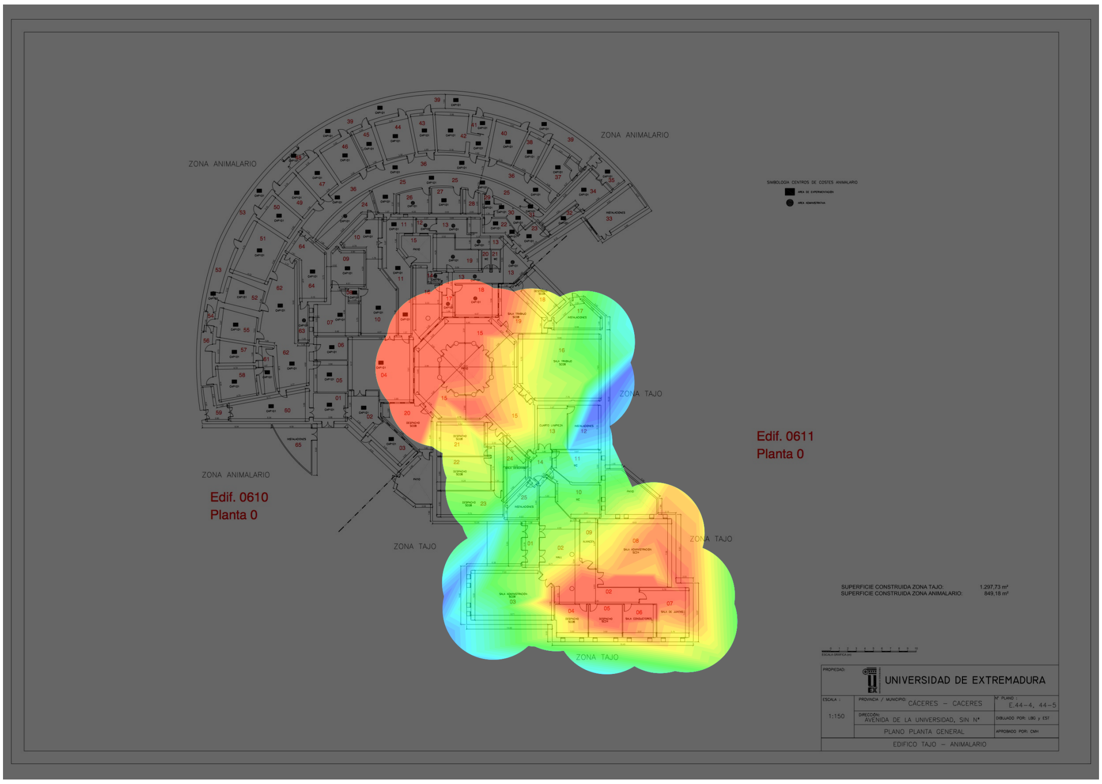
We see the location of the building on the following plan.



4.14.1. Building 0611 Floor 0

4.14.1.1. Signal to Noise Ratio

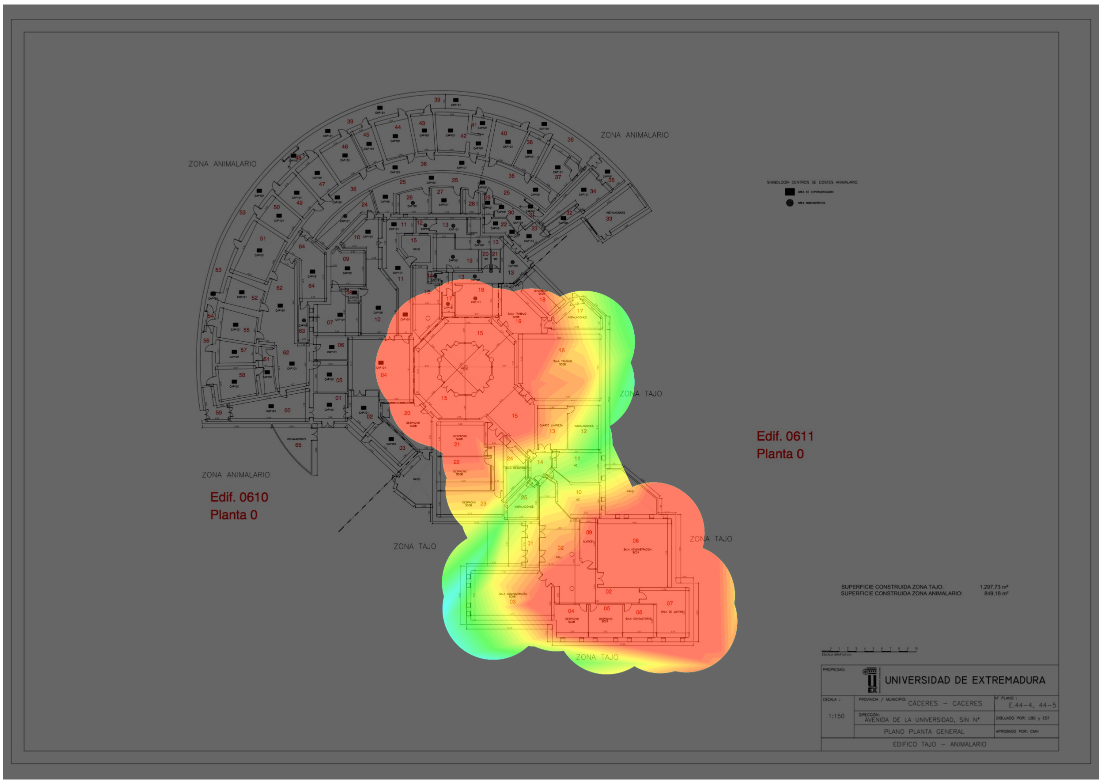
In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.



The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.14.1.2. Signal Level



We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

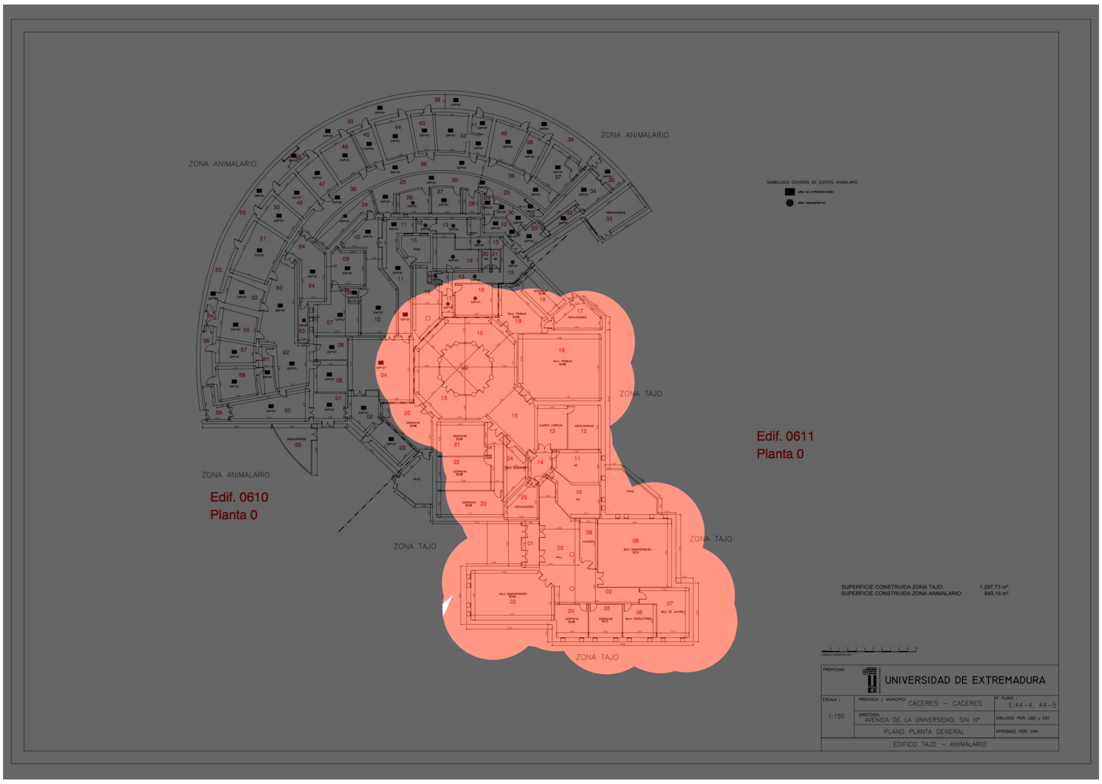
- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.14.1.3. Number of Access Points

In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.14.1.4. Coverage per Frequency Band

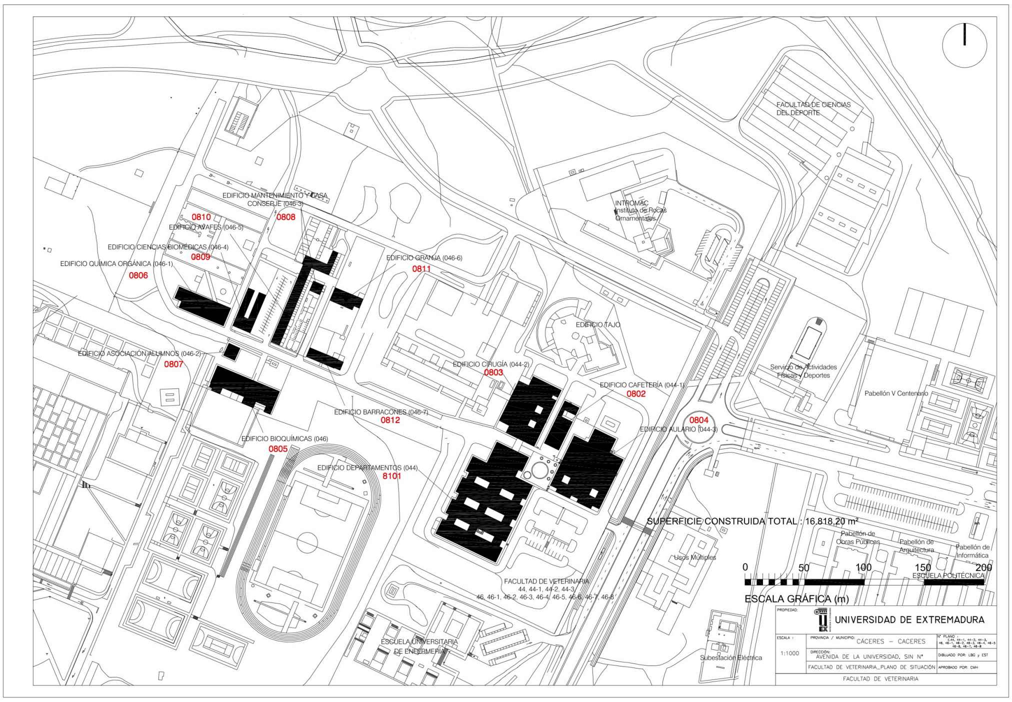


In the illustration we can see that only available the coverage in the case of 2.4 GHz.

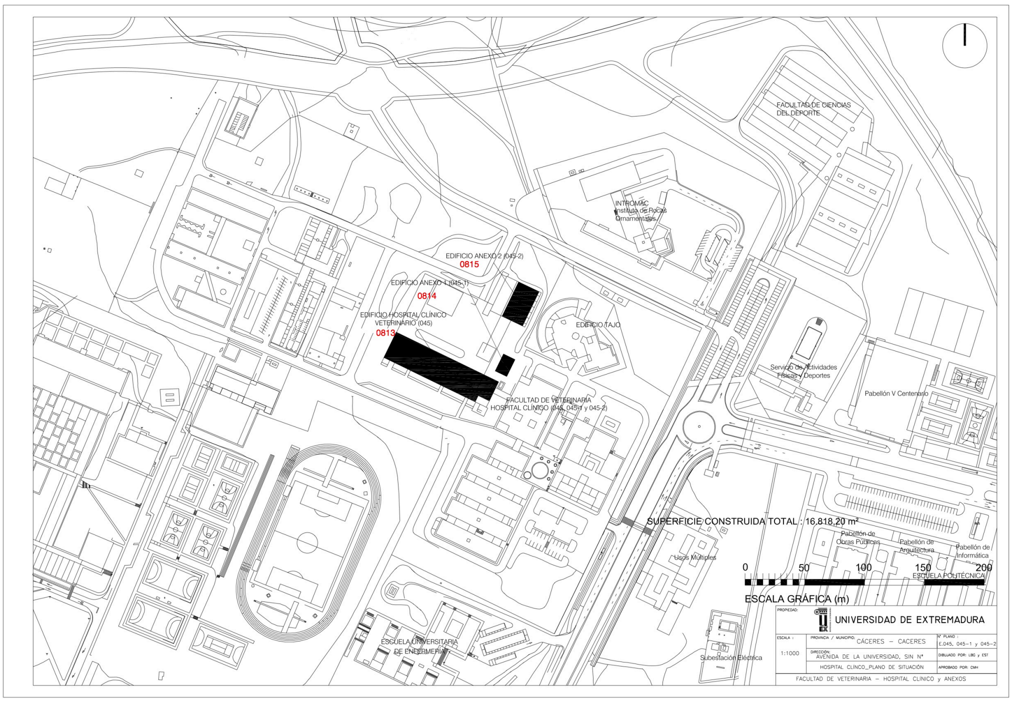
4.15. Facultad de Veterinaria y Hospital Clínico Veterinario

A total of 818 measurement points were taken along the surface to develop the following heat maps where we can observe the following aspects.

We see the location of the faculty on the following plan.



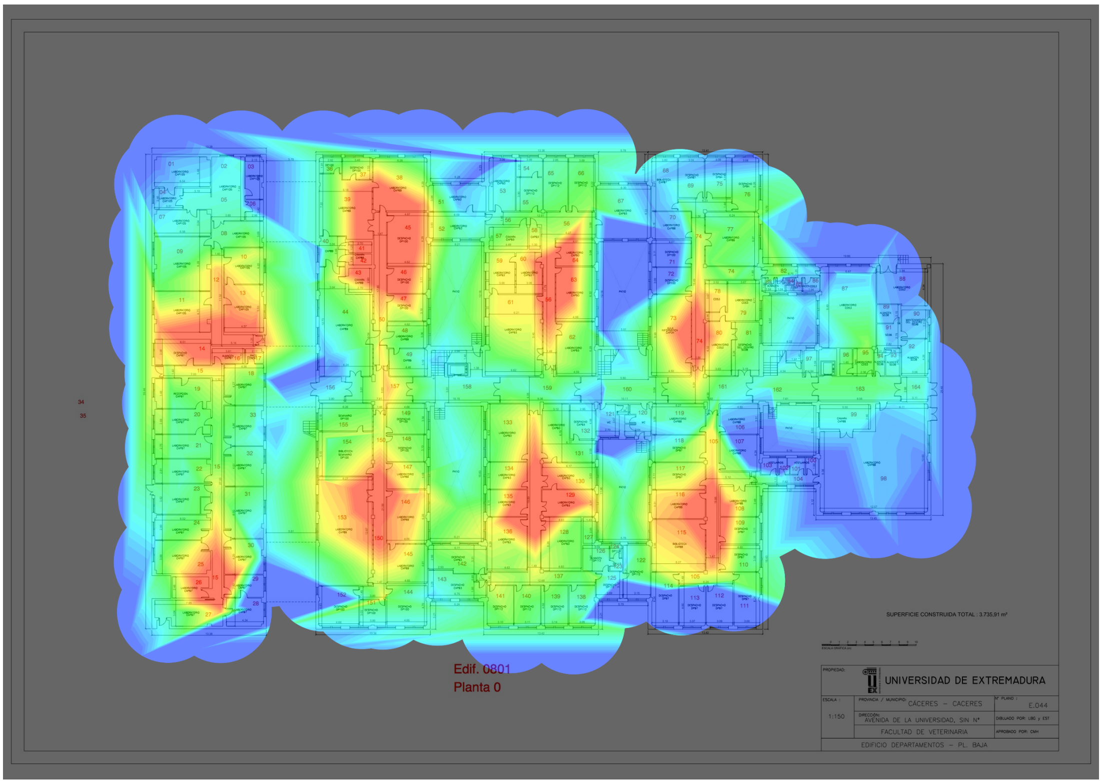
We see the location of the Clinic Hospital on the following plan.



4.15.1. Building 0801 Floor 0

4.15.1.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

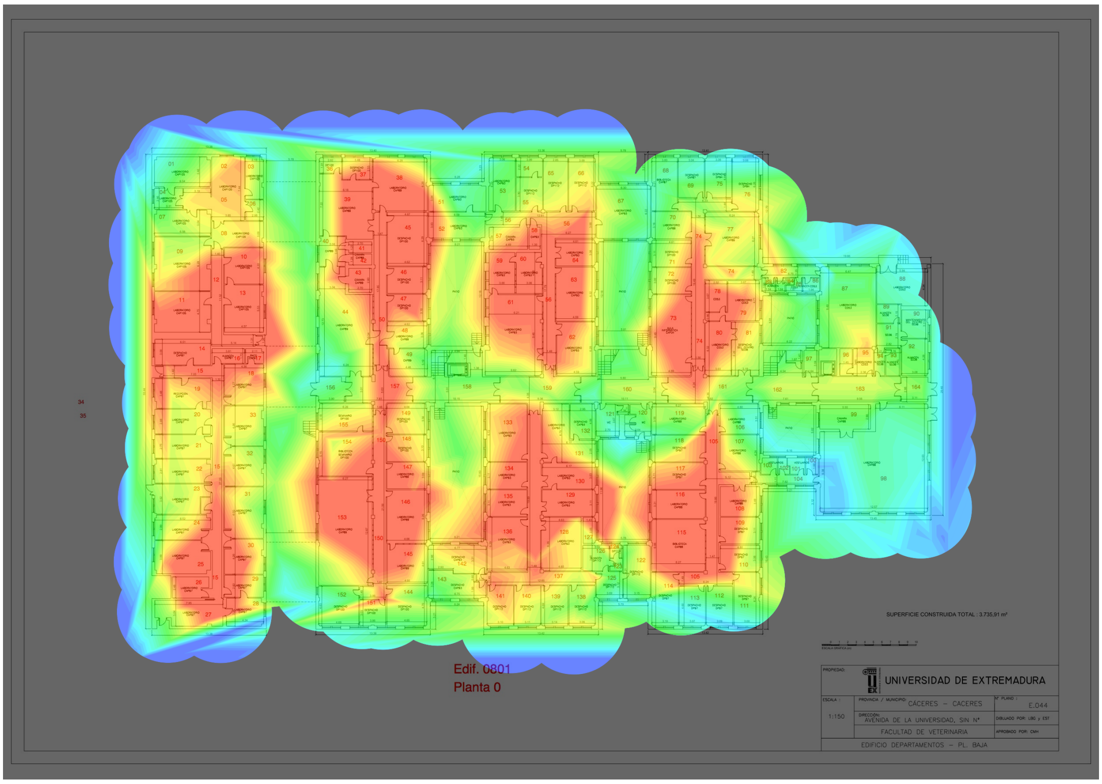


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.1.2. Signal Level



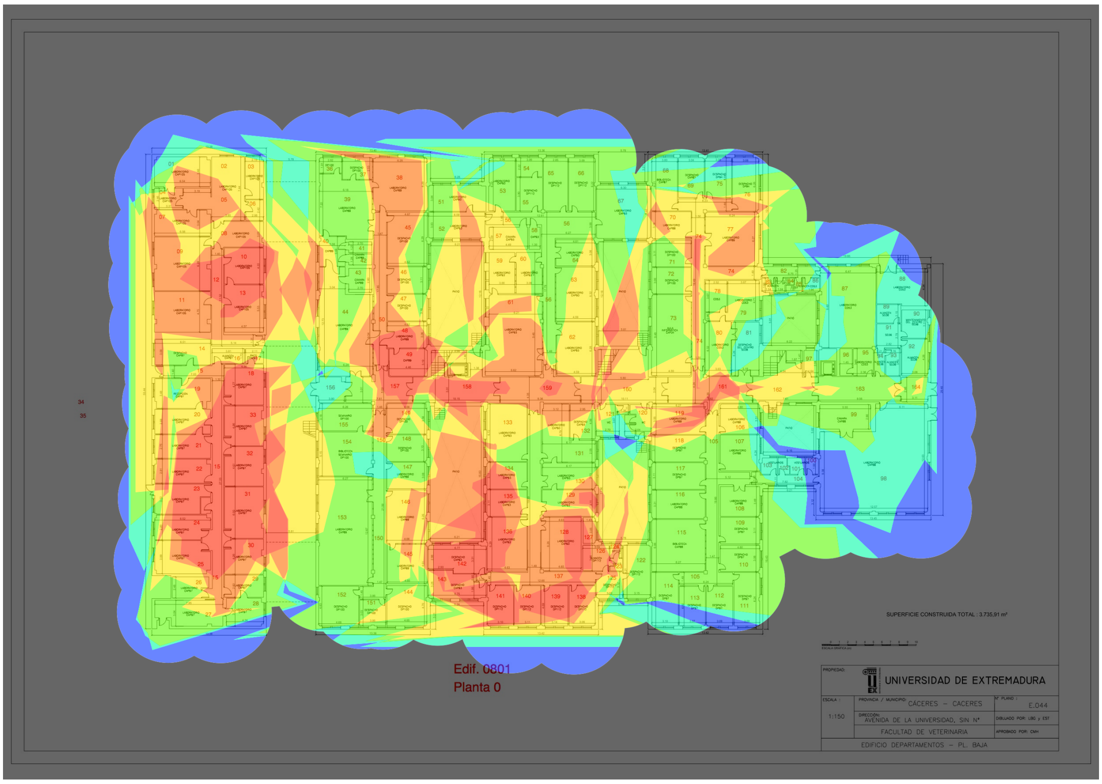
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.15.1.3. Number of Access Points

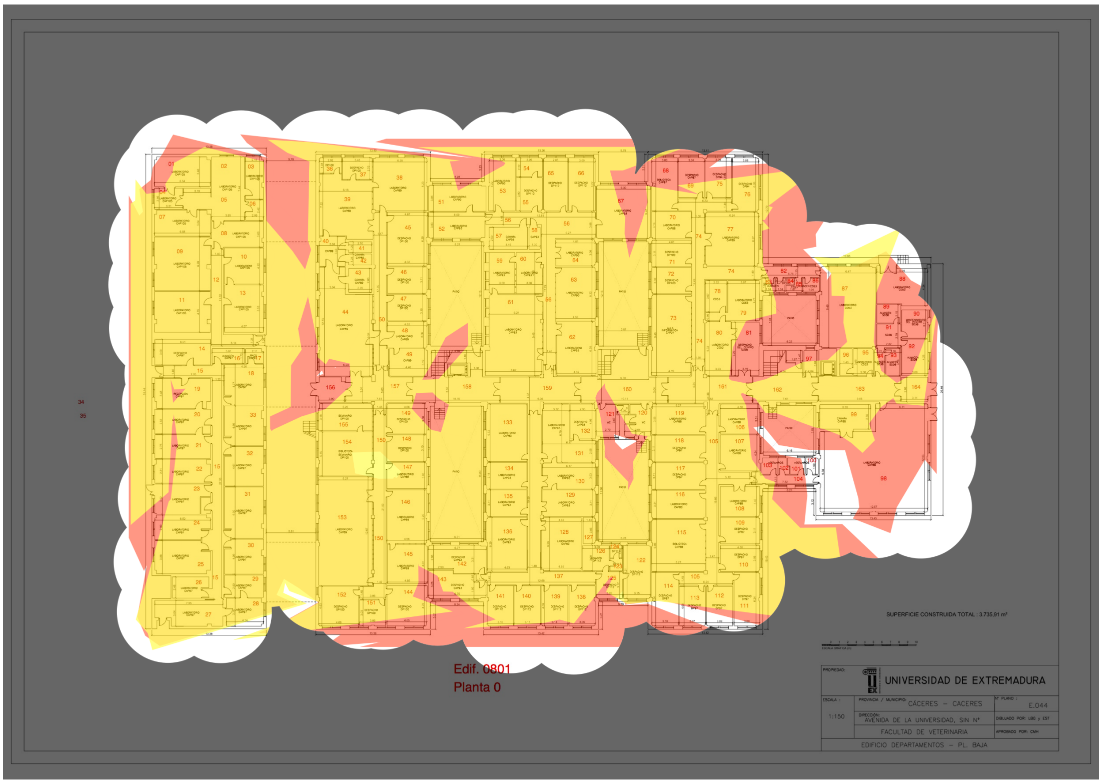


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.1.4. Coverage per Frequency Band



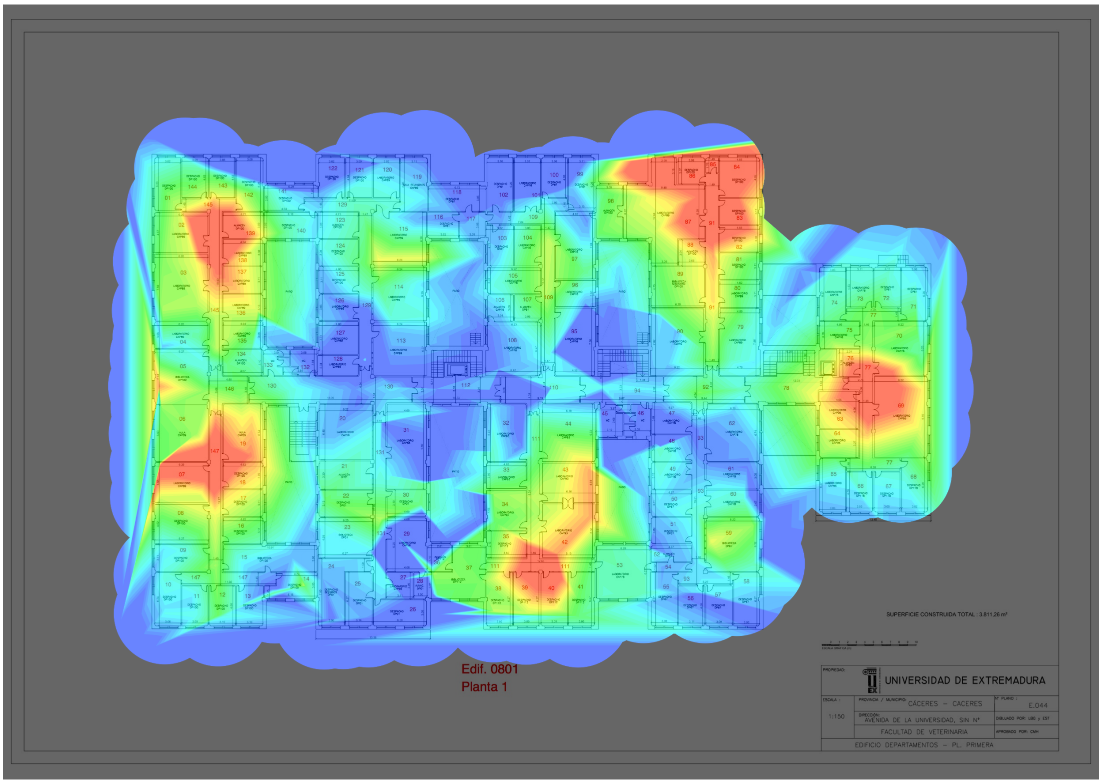
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.15.2. Building 0801 Floor 1

4.15.2.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

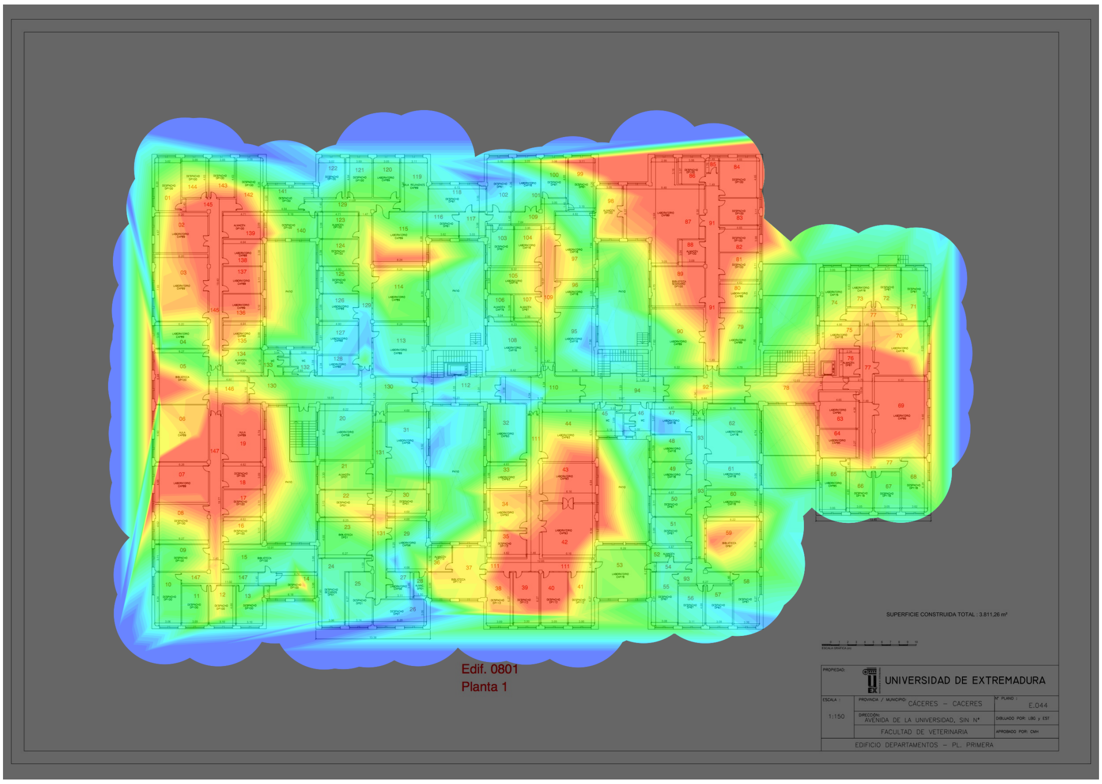


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.2.2. Signal Level



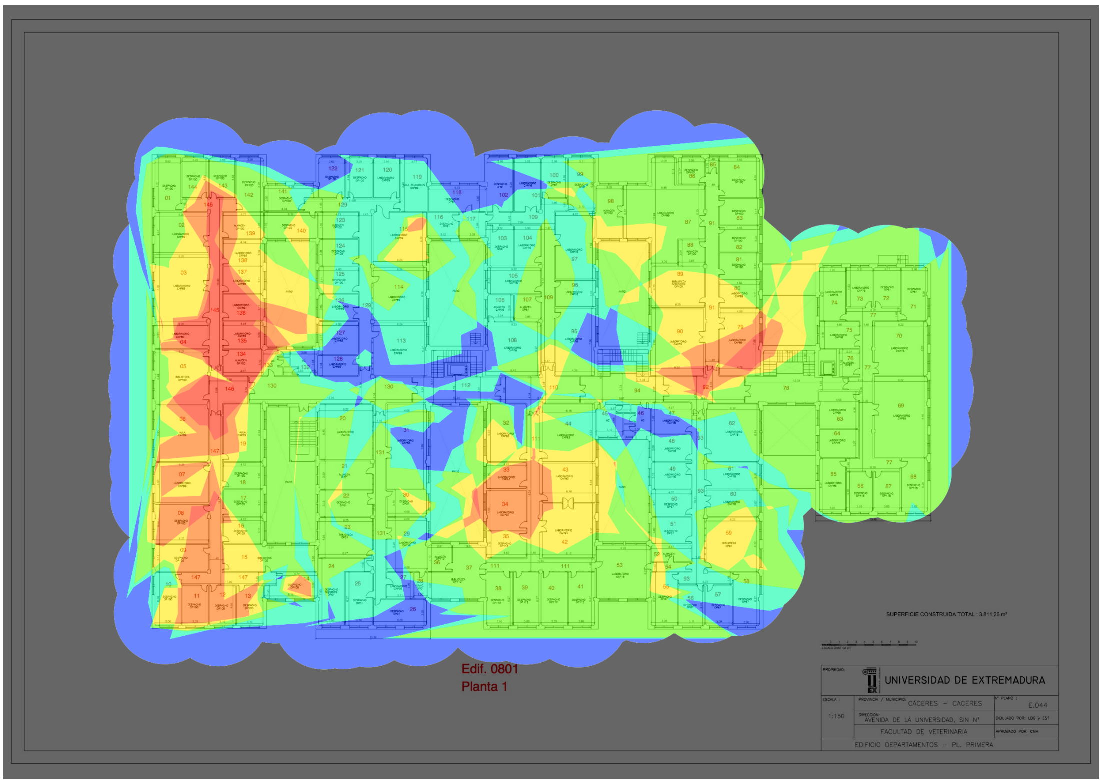
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.15.2.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.2.4. Coverage per Frequency Band

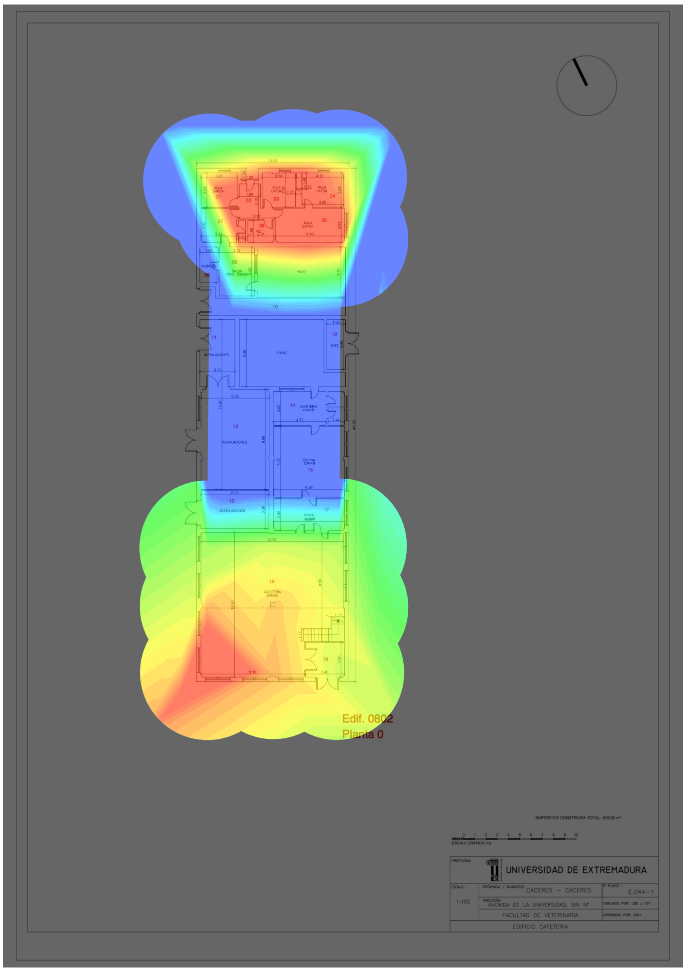
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.15.11. Building 0802 Floor 0

4.15.11.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

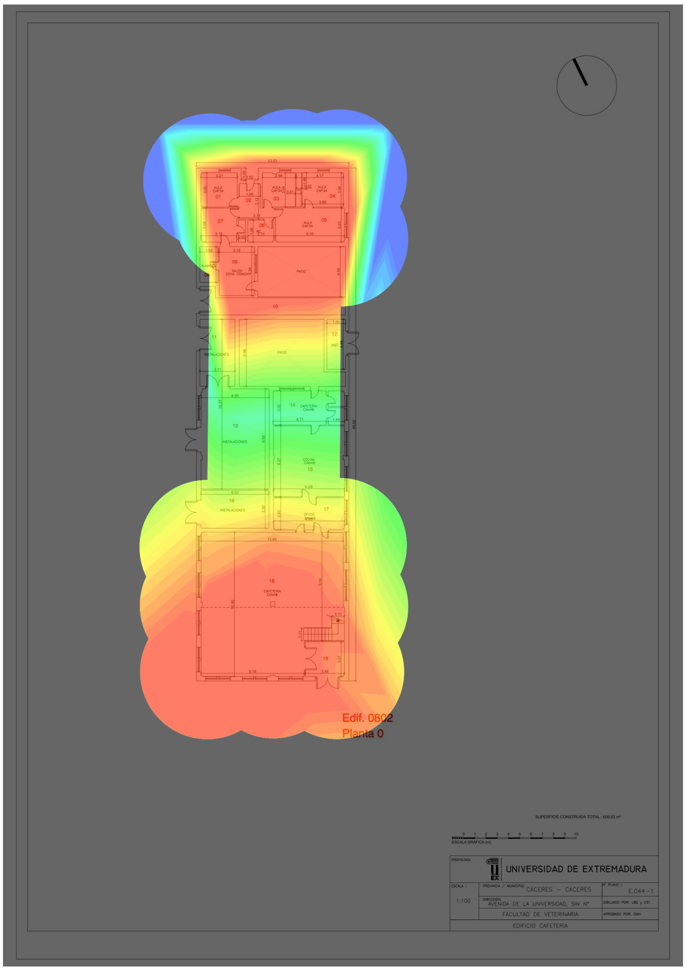


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.11.2. Signal Level



In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

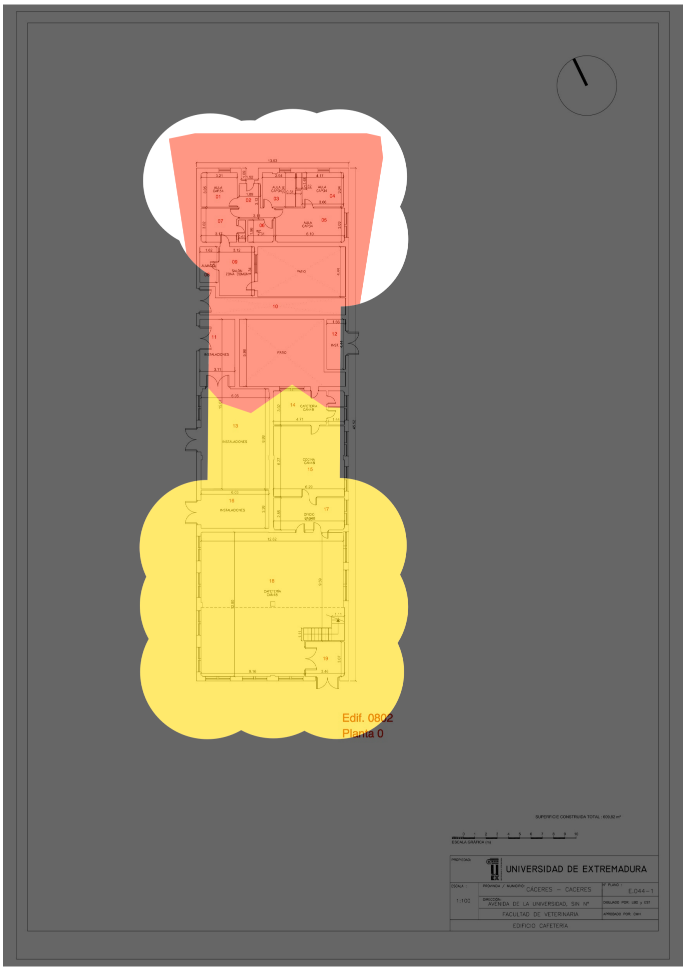
4.15.11.3. Number of Access Points

In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.11.4. Coverage per Frequency Band



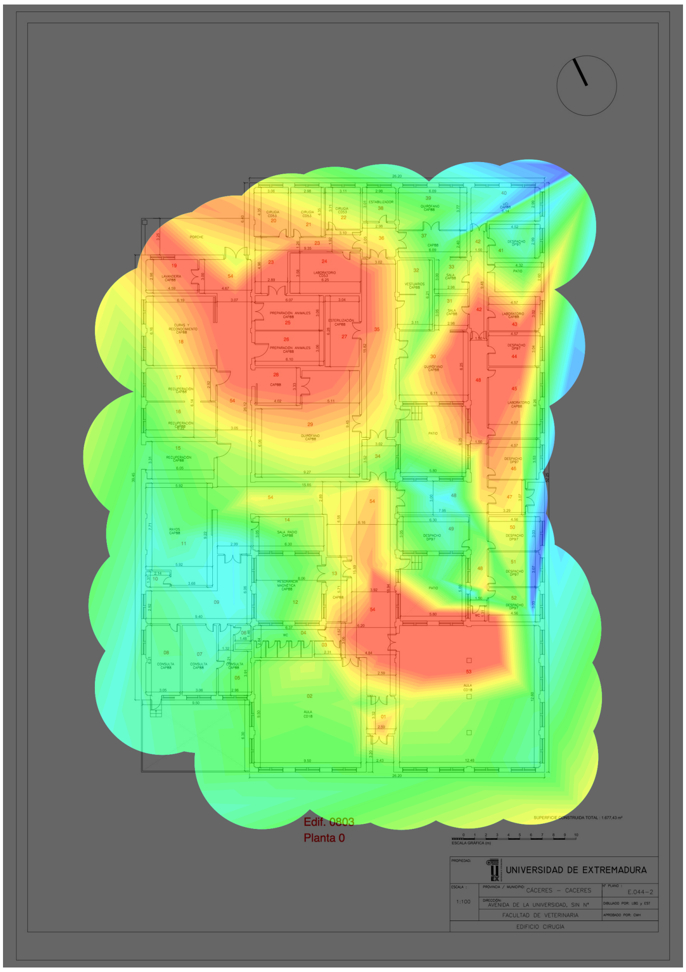
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.15.21. Building 0803 Floor 0

4.15.21.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

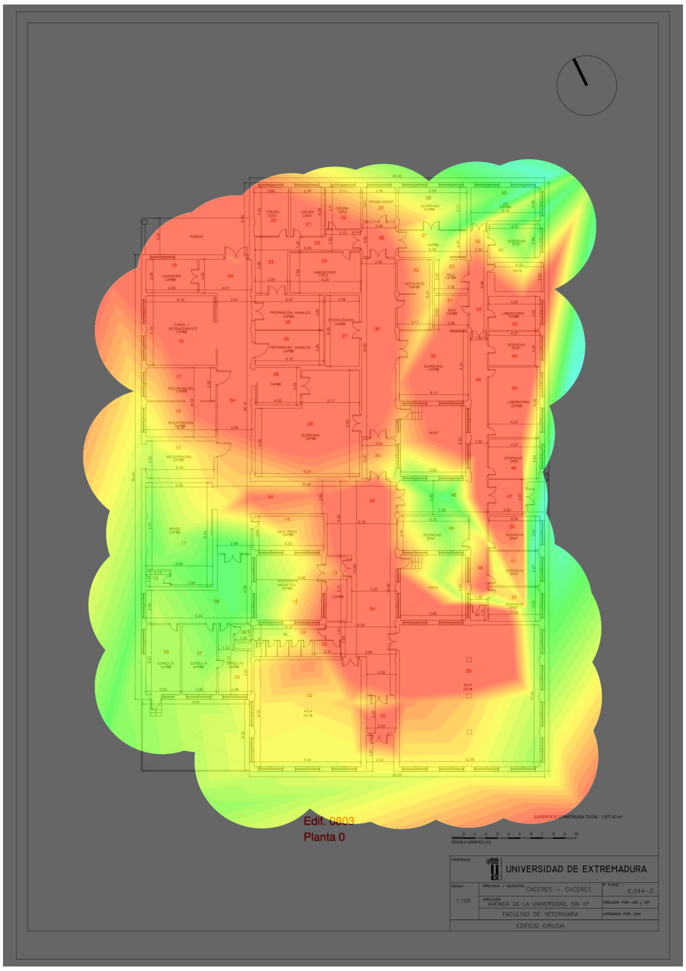


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.21.2. Signal Level



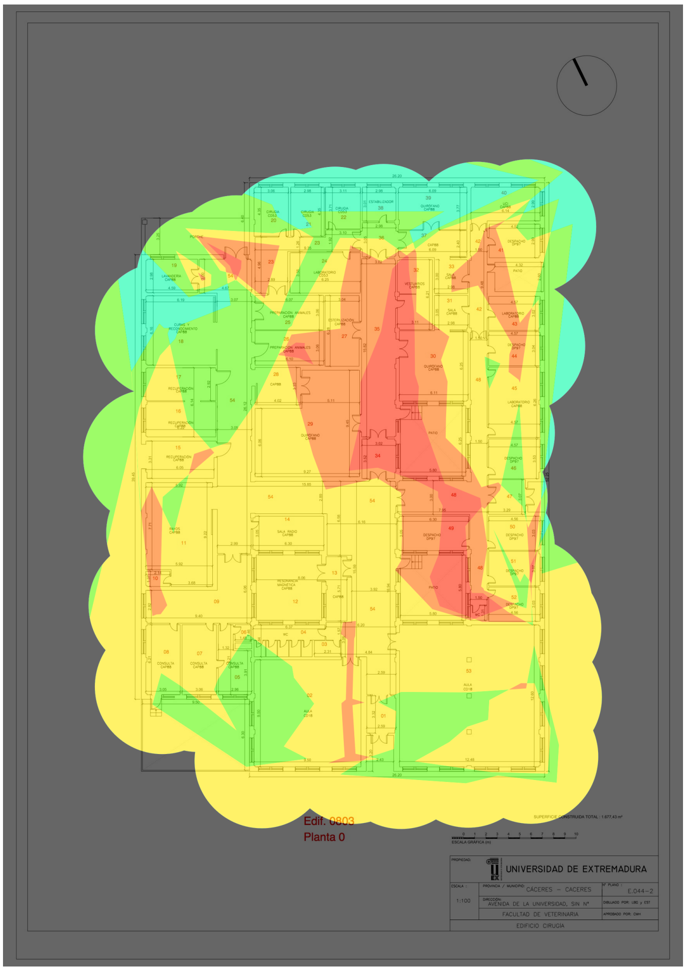
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.15.21.3. Number of Access Points

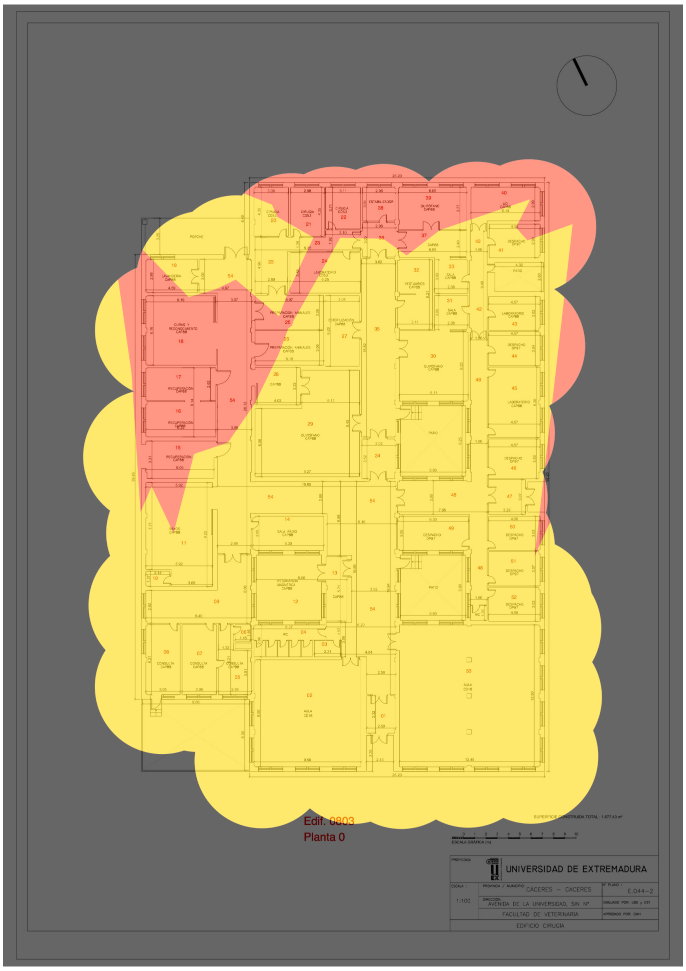


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.21.4. Coverage per Frequency Band

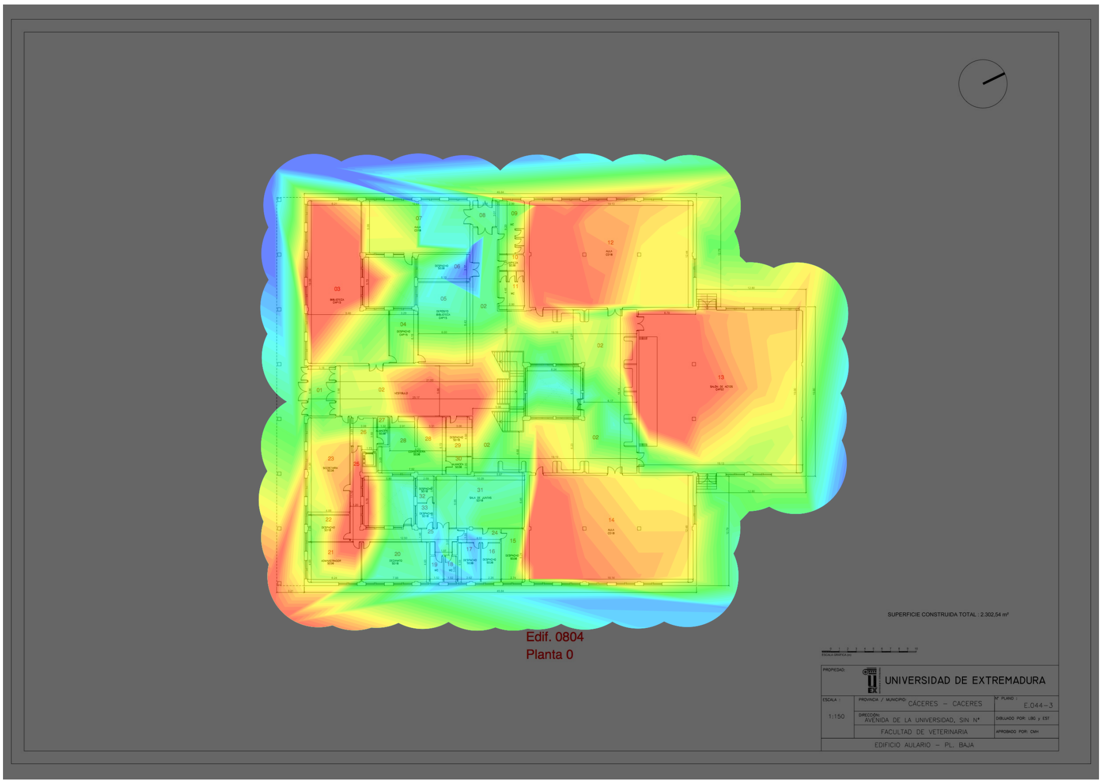


In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

4.15.31. Building 0804 Floor 0

4.15.31.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

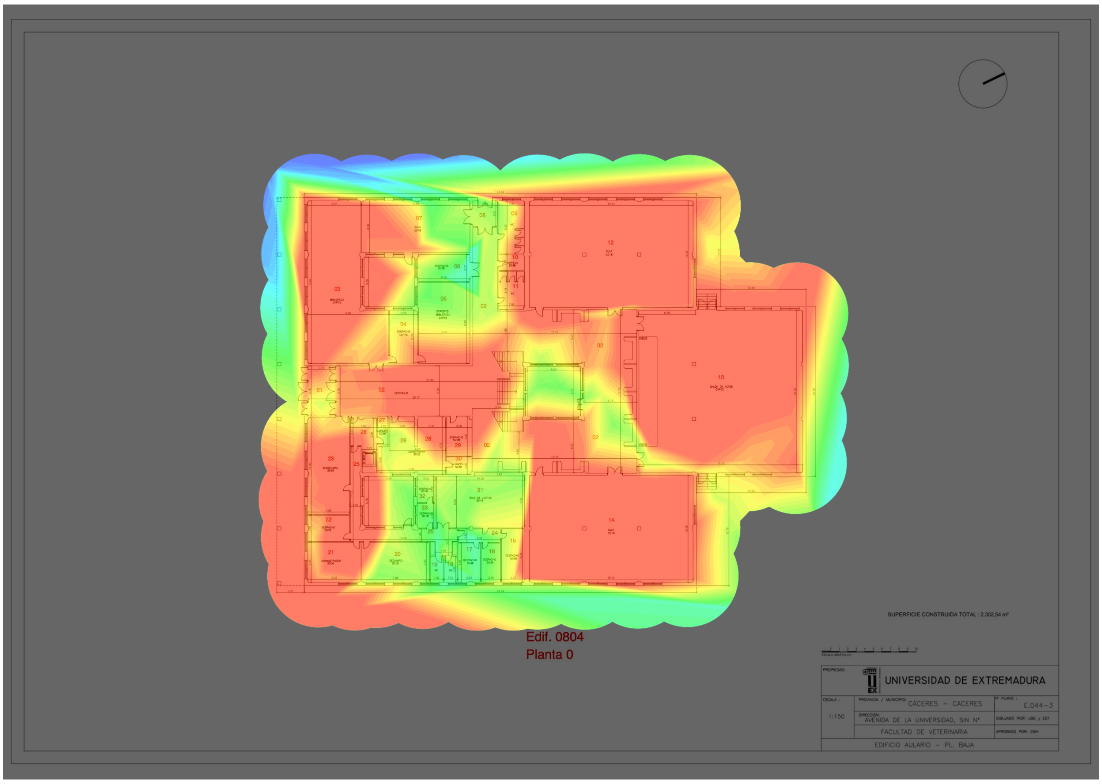


It can be seen that the areas where the classrooms and the library are placed are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.31.2. Signal Level



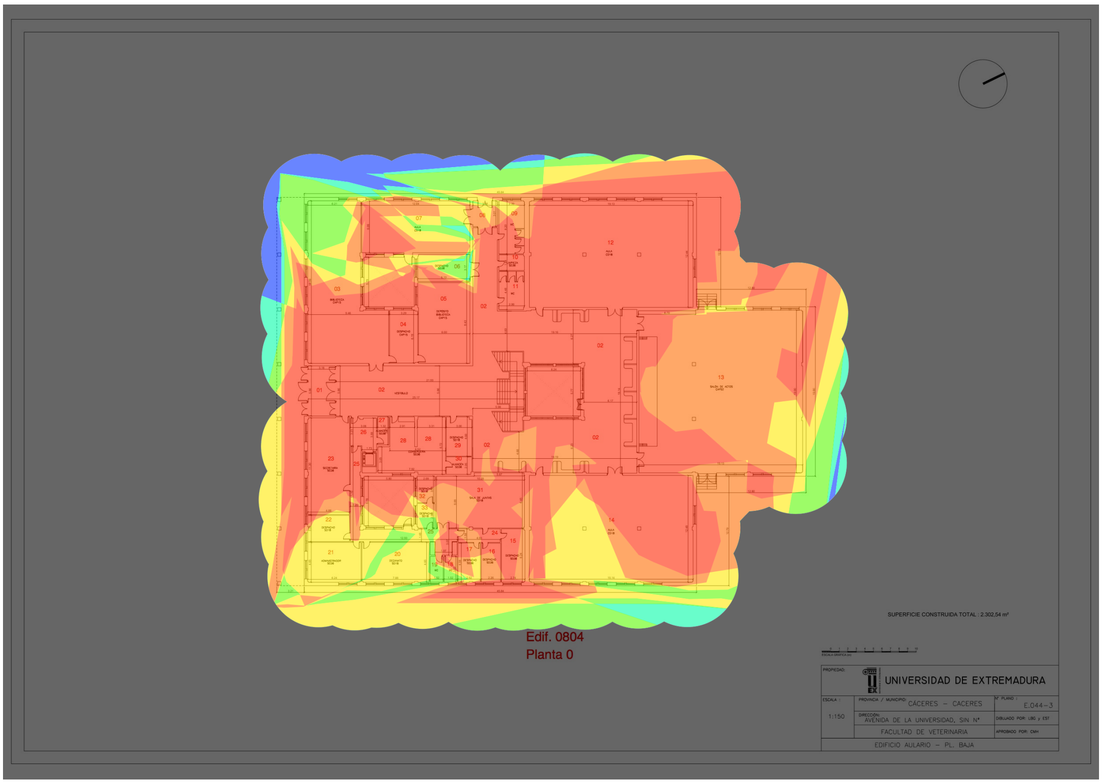
In this picture we can see again how the signal level in the areas of the classrooms and the library, are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.15.31.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.31.4. Coverage per Frequency Band

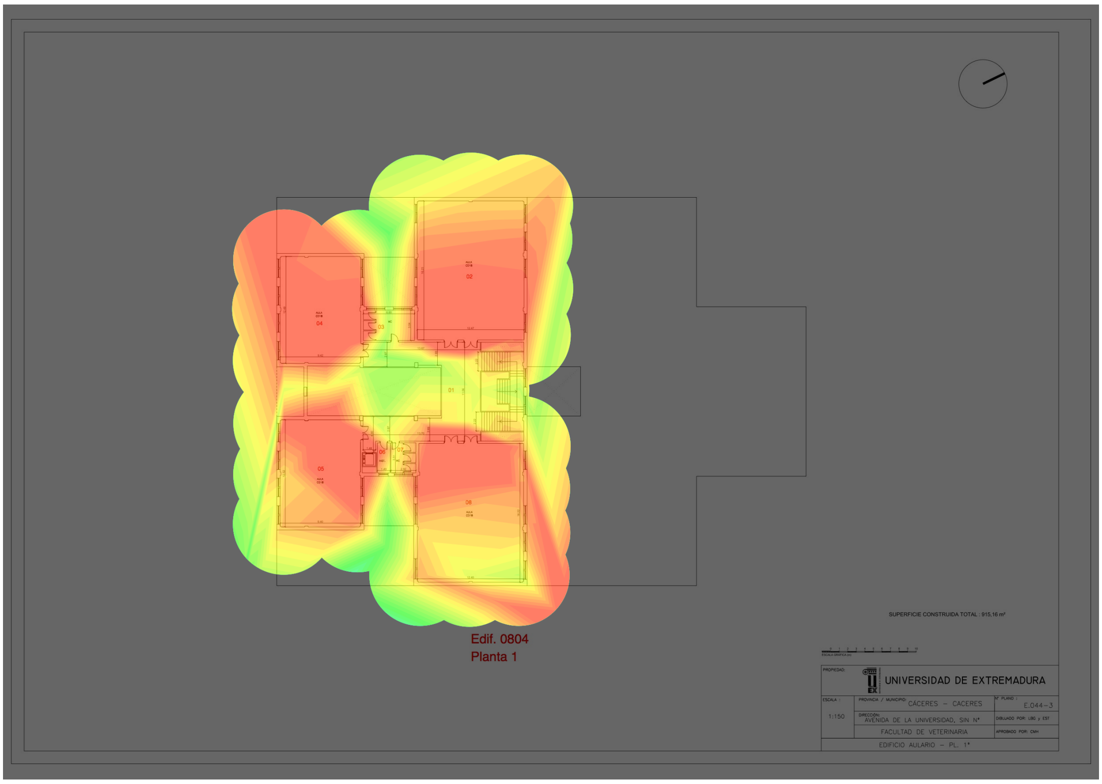
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.15.32. Building 0804 Floor 1

4.15.32.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

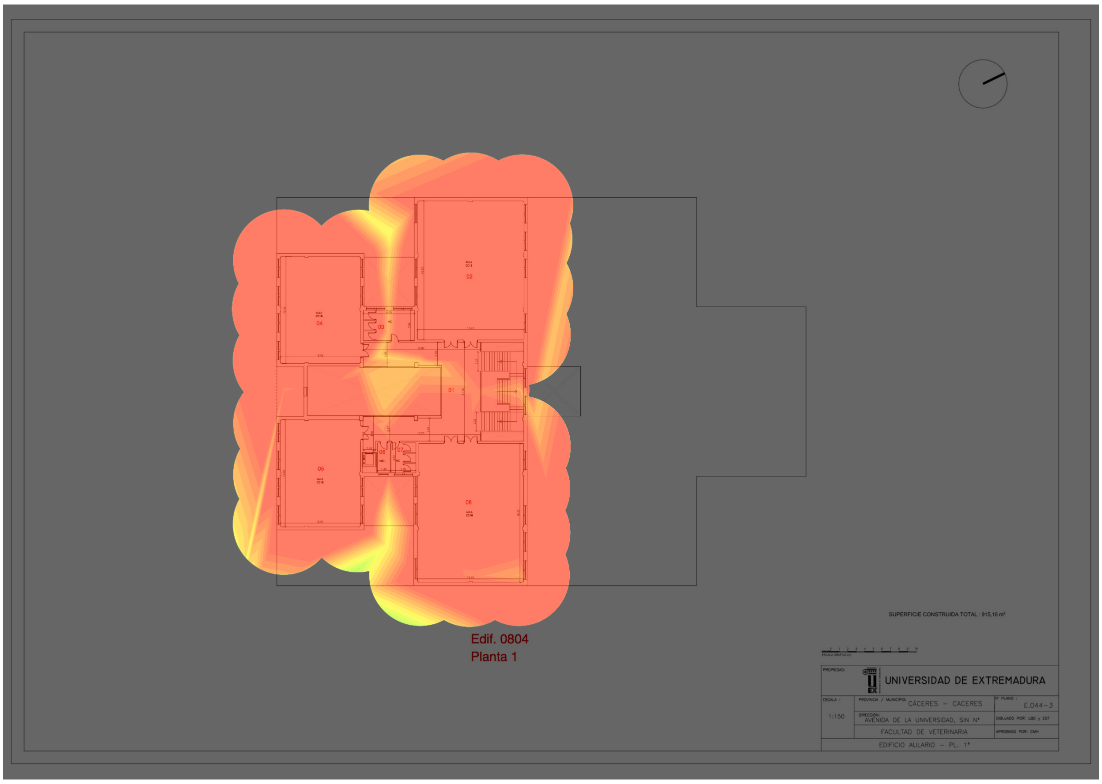


It can be seen that the areas where the classrooms are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.32.2. Signal Level



In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

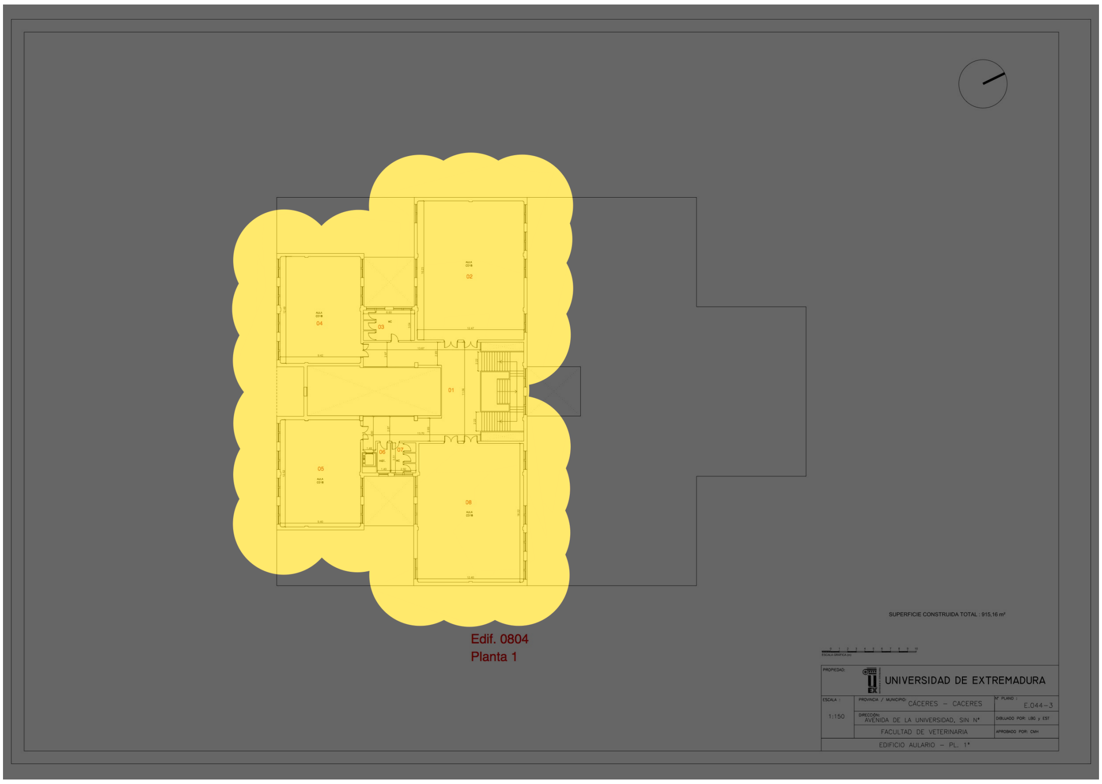
4.15.32.3. Number of Access Points

In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.32.4. Coverage per Frequency Band

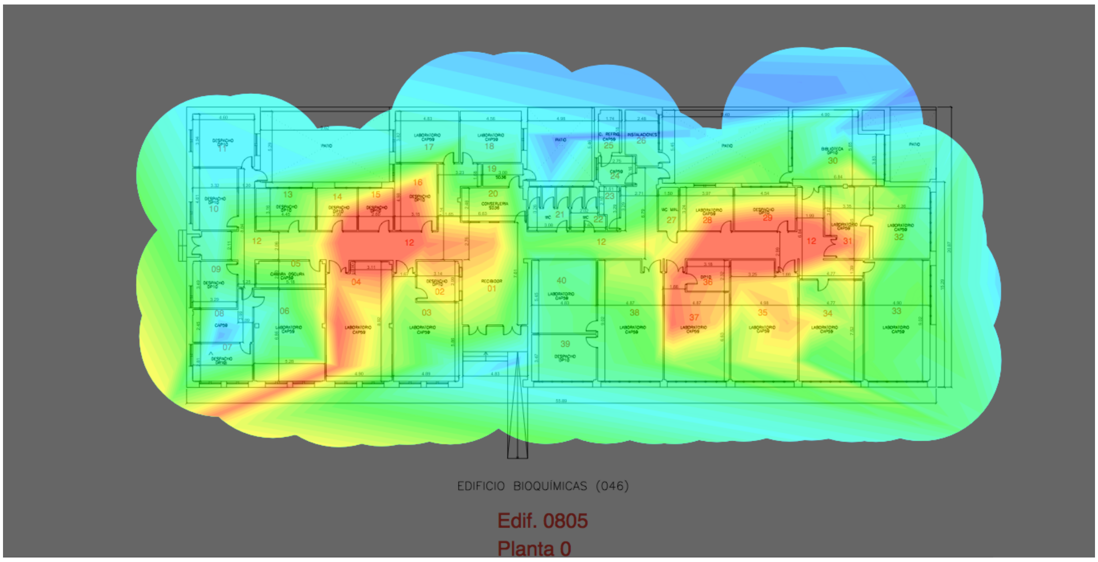


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.15.41. Building 0805 Floor 0

4.15.41.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

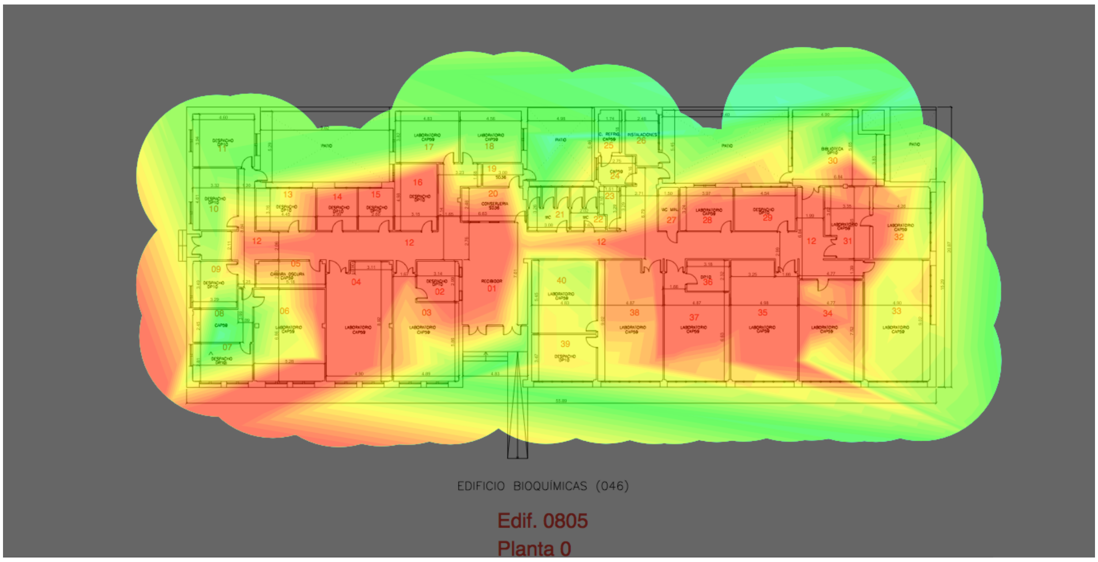


It can be seen that the areas where the classrooms are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.41.2. Signal Level



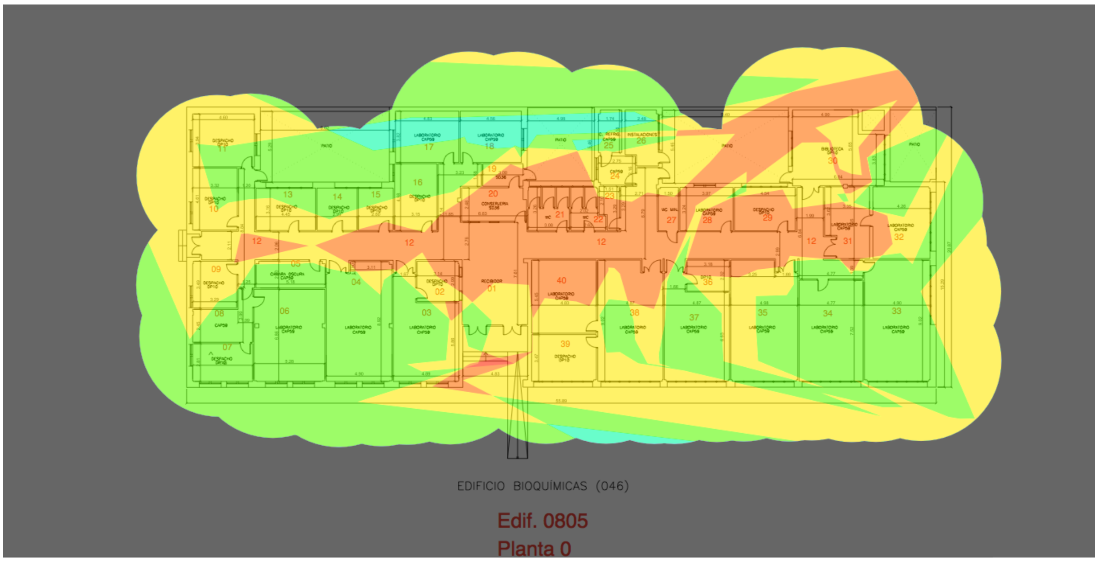
In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.15.41.3. Number of Access Points

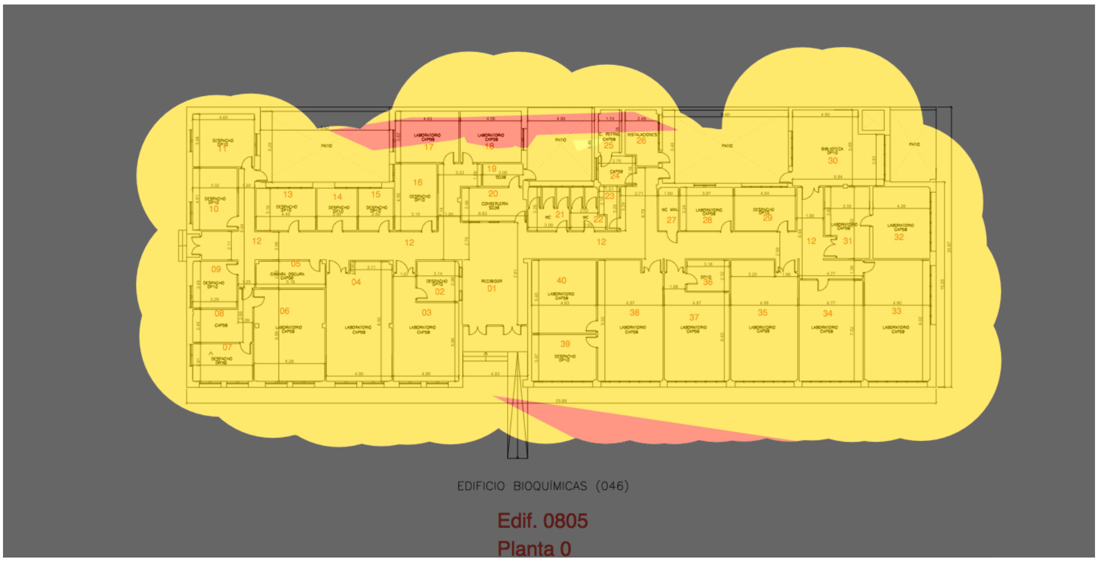


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.41.4. Coverage per Frequency Band



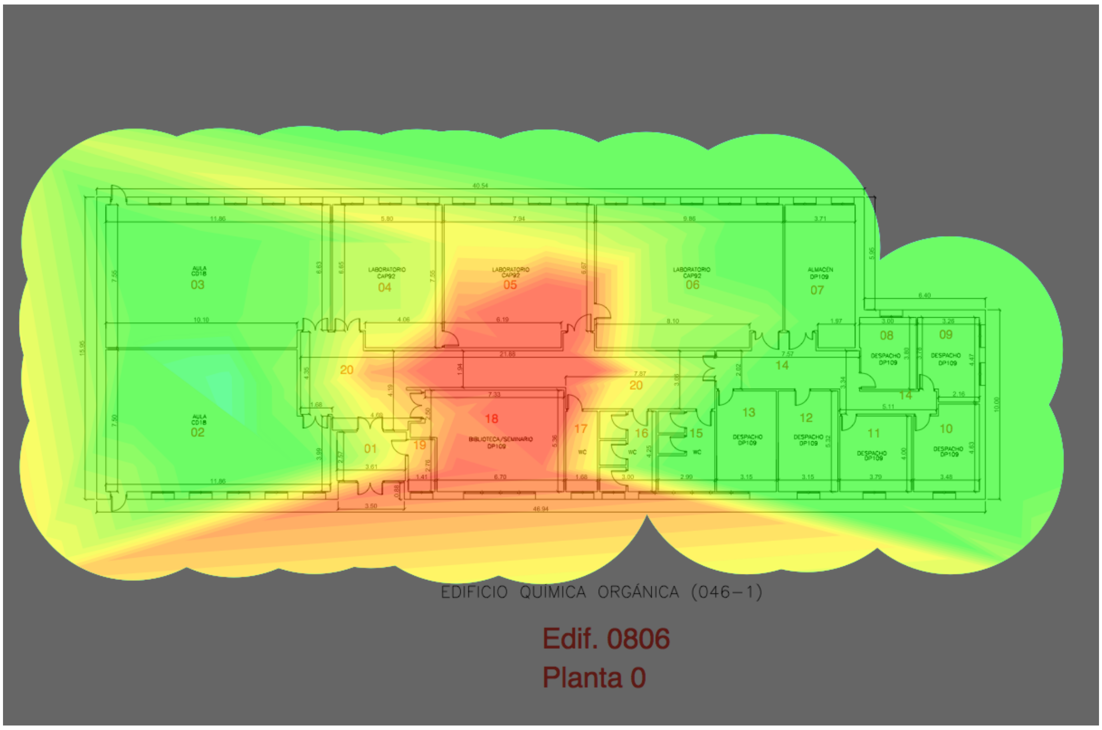
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.15.51. Building 0806 Floor 0

4.15.51.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

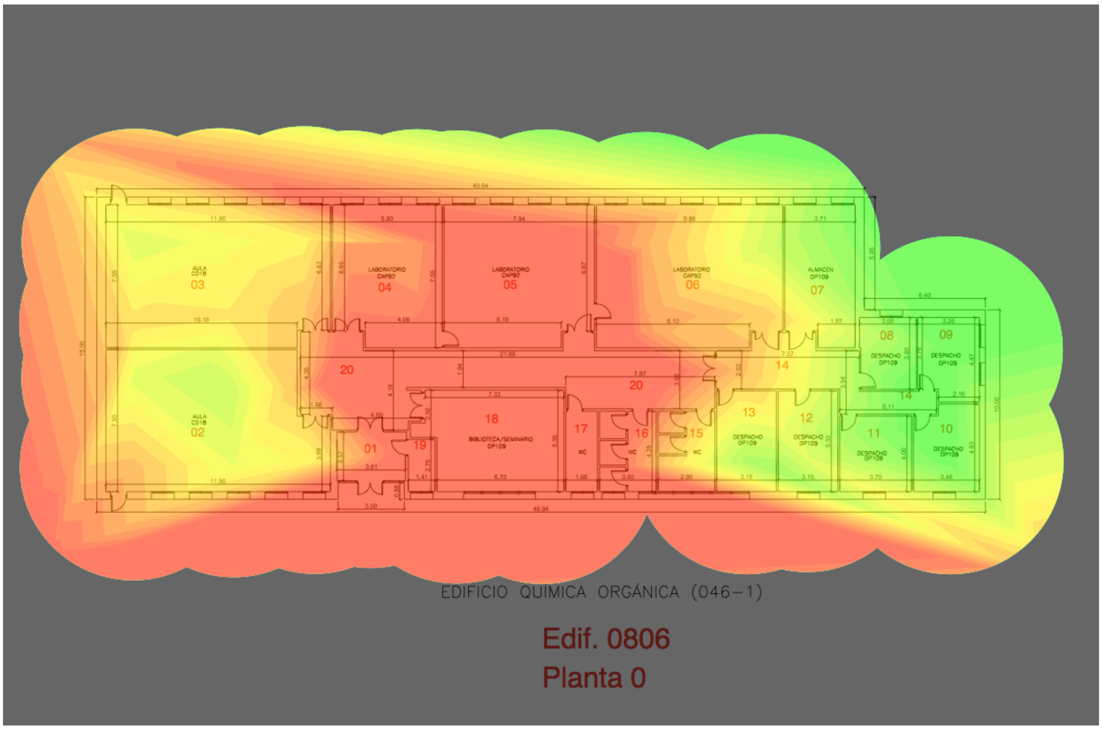


It can be seen that the areas where the classrooms are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.51.2. Signal Level



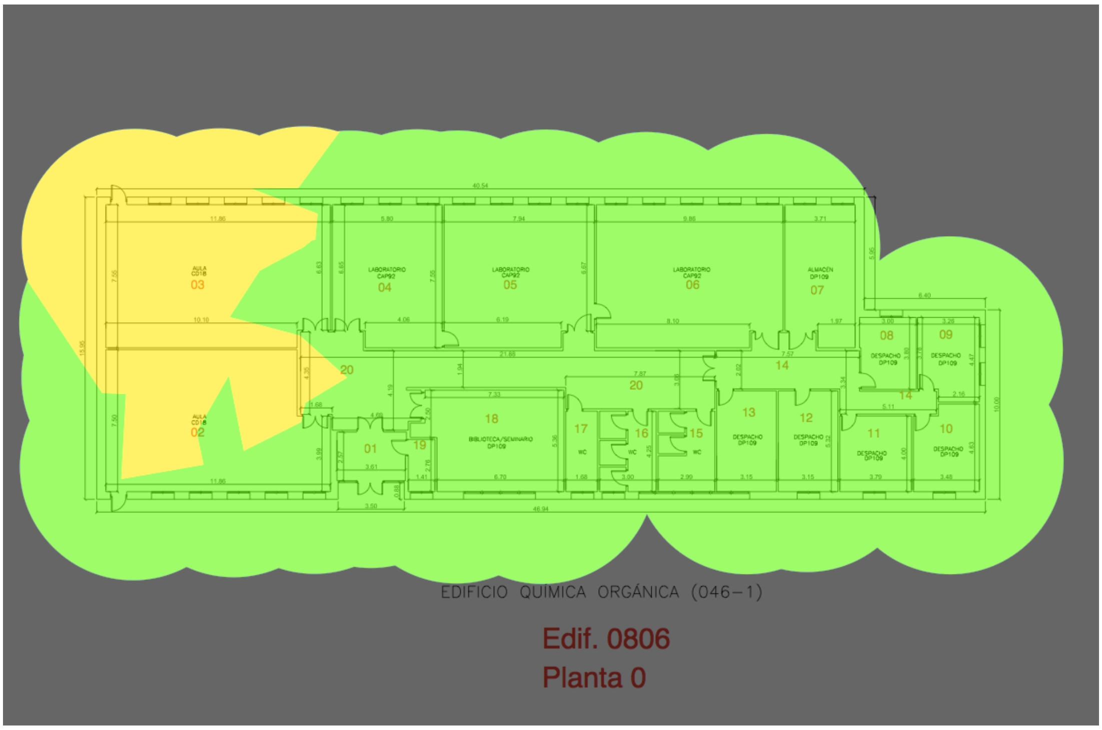
In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.15.51.3. Number of Access Points

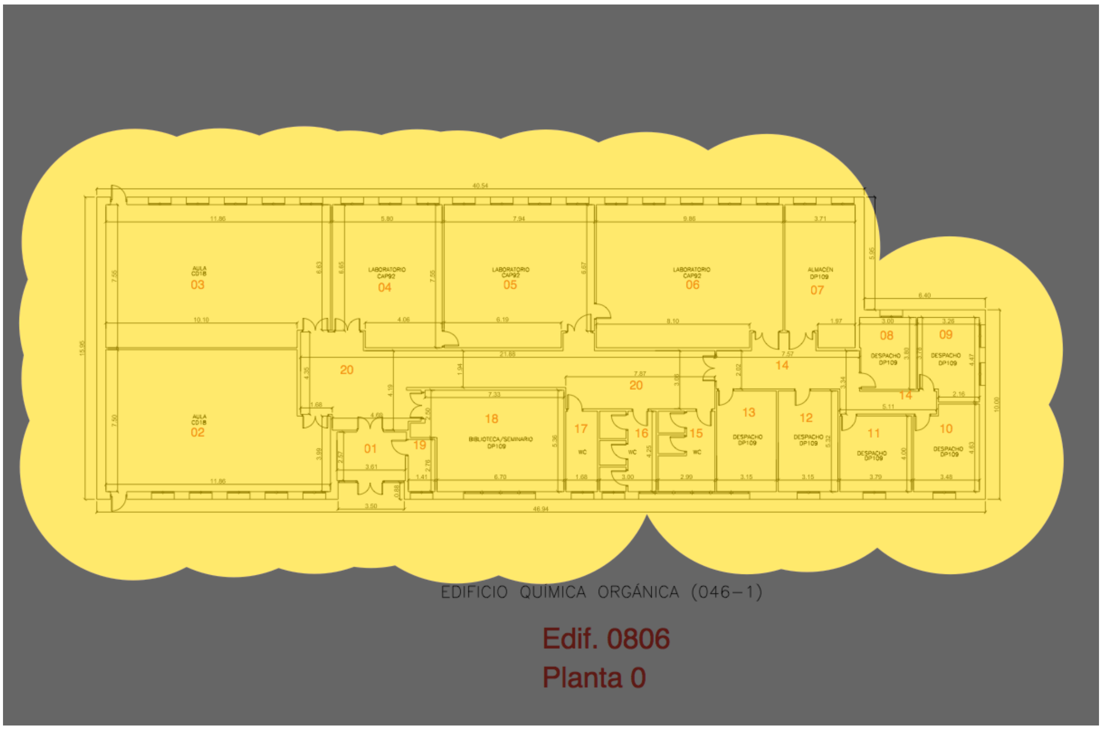


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.51.4. Coverage per Frequency Band

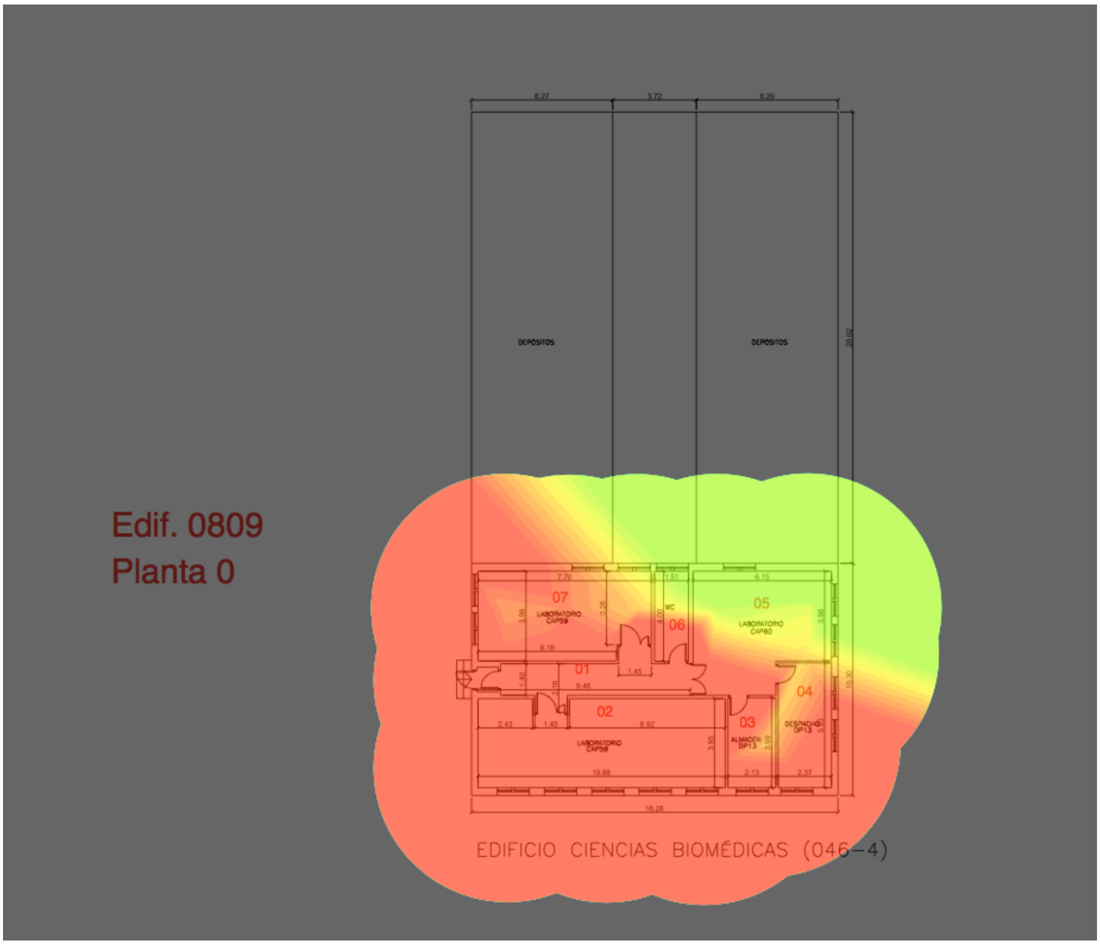


In the illustration we can see as equal coverage in both frequencies. This is because the building has little surface and comes out perfectly 5GHz signal.

4.15.61. Building 0809 Floor 0

4.15.61.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

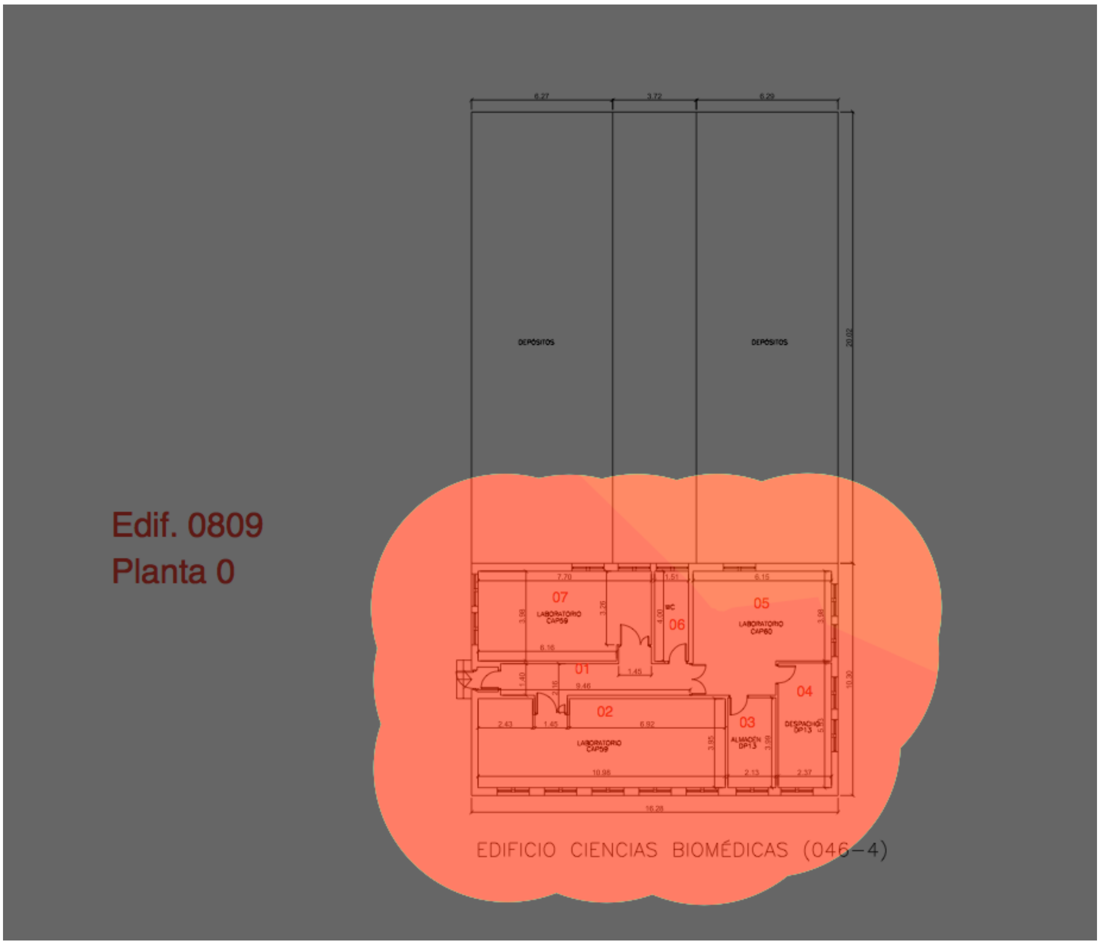


It can be seen that the areas where the classrooms are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.61.2. Signal Level



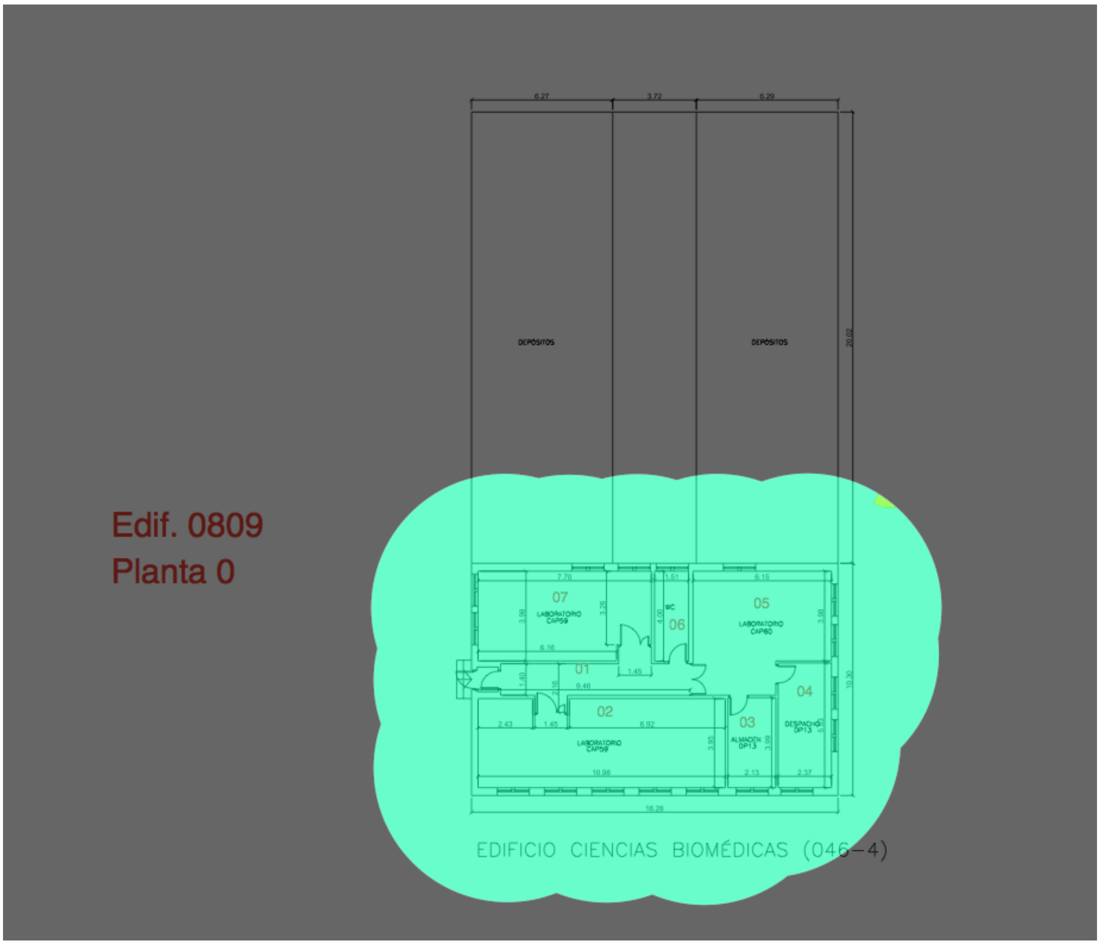
In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

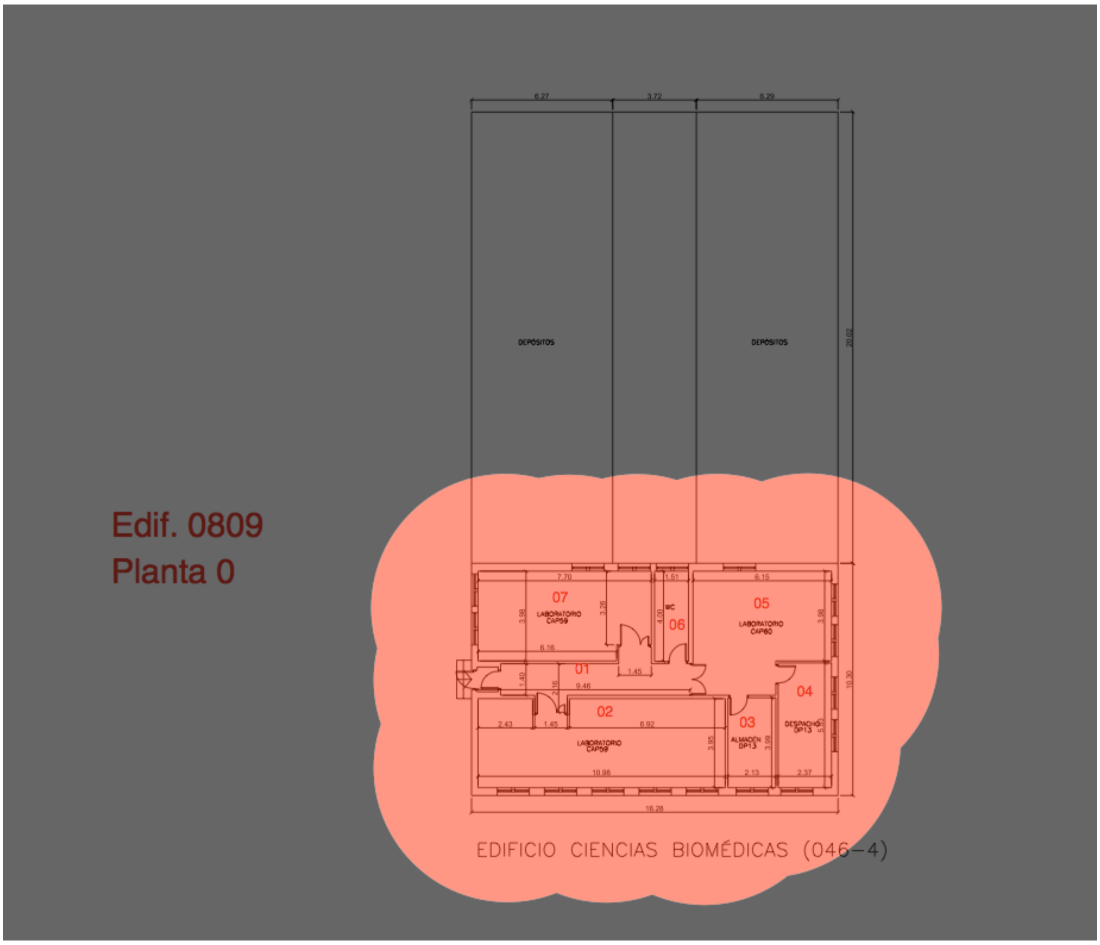
4.15.61.3. Number of Access Points



In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.61.4. Coverage per Frequency Band

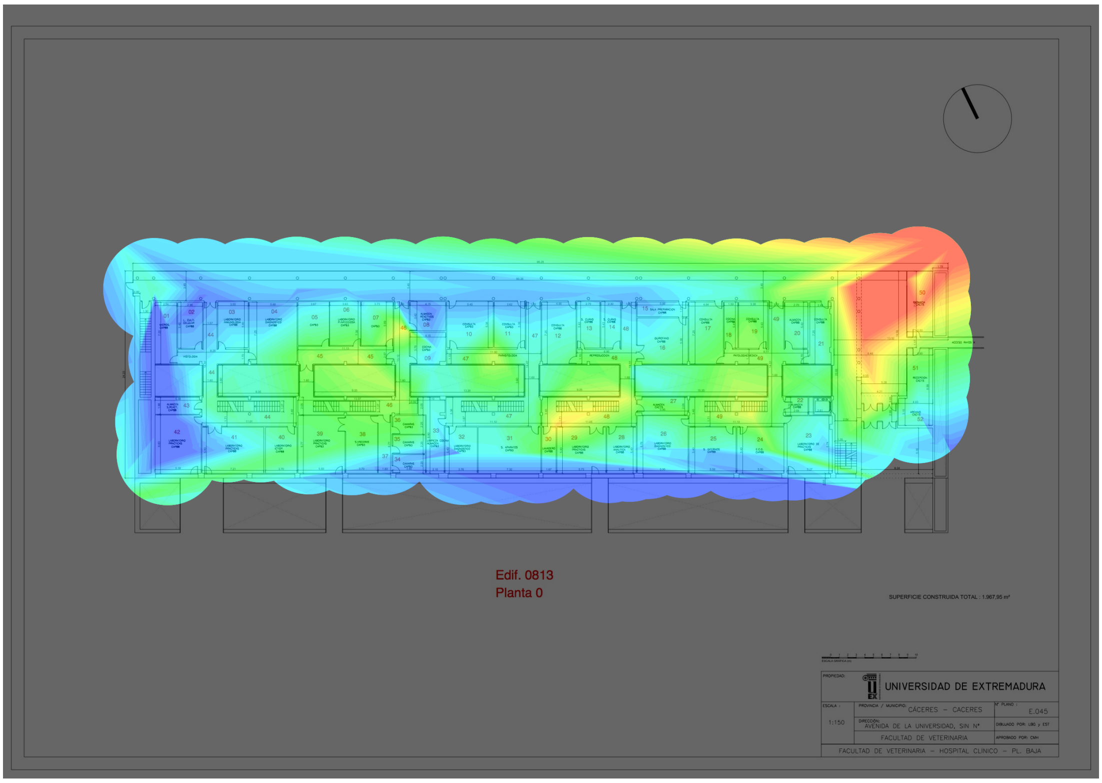


In the illustration we can see that only available the coverage in the case of 2.4 GHz.

4.15.71. Building 0813 Floor 0

4.15.71.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

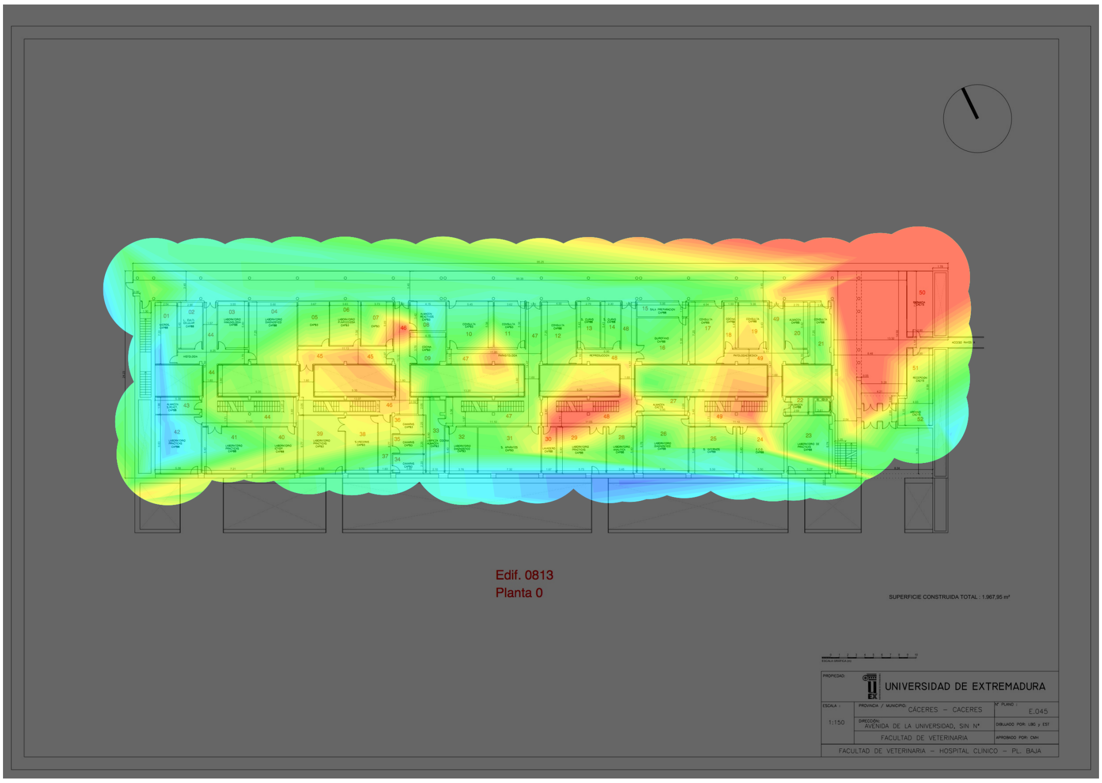


It can be seen that the areas where the classrooms are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.71.2. Signal Level



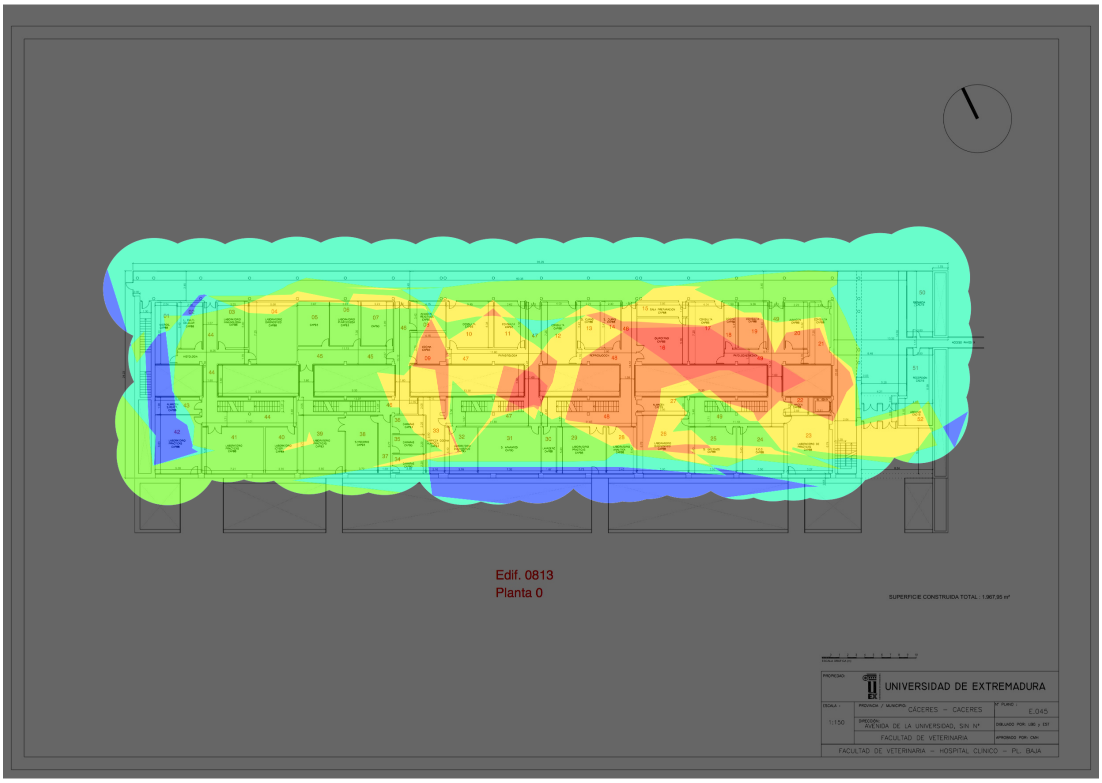
In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.15.71.3. Number of Access Points

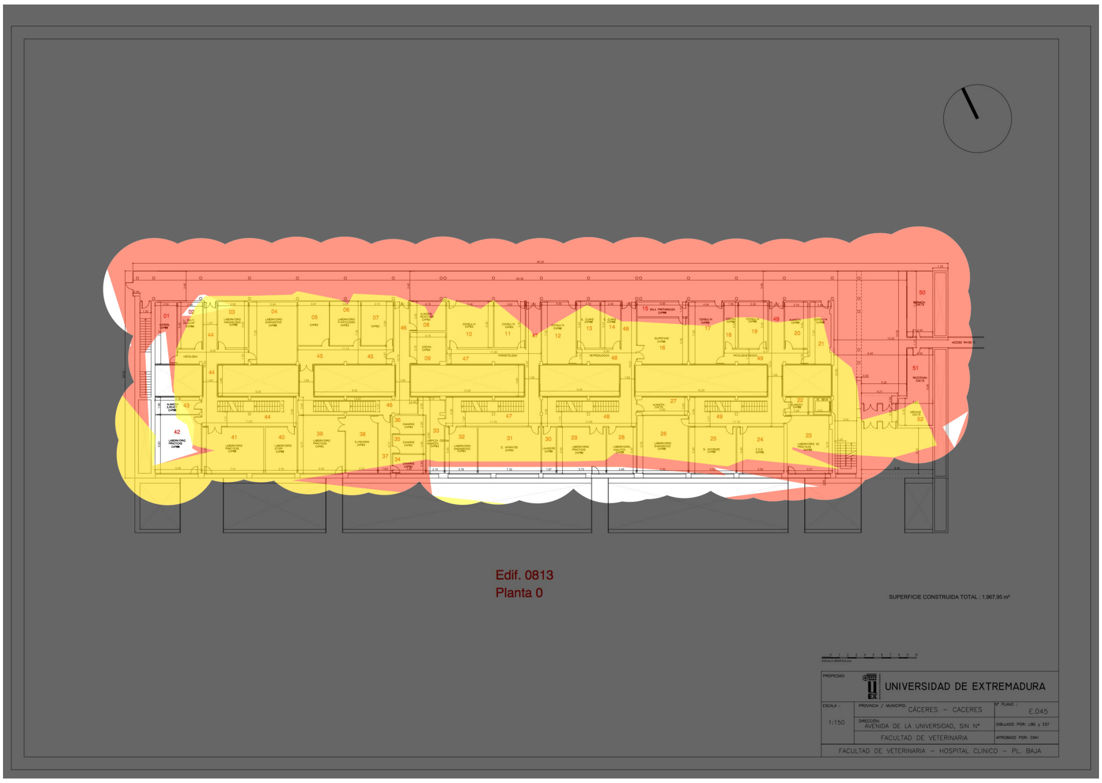


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.71.4. Coverage per Frequency Band



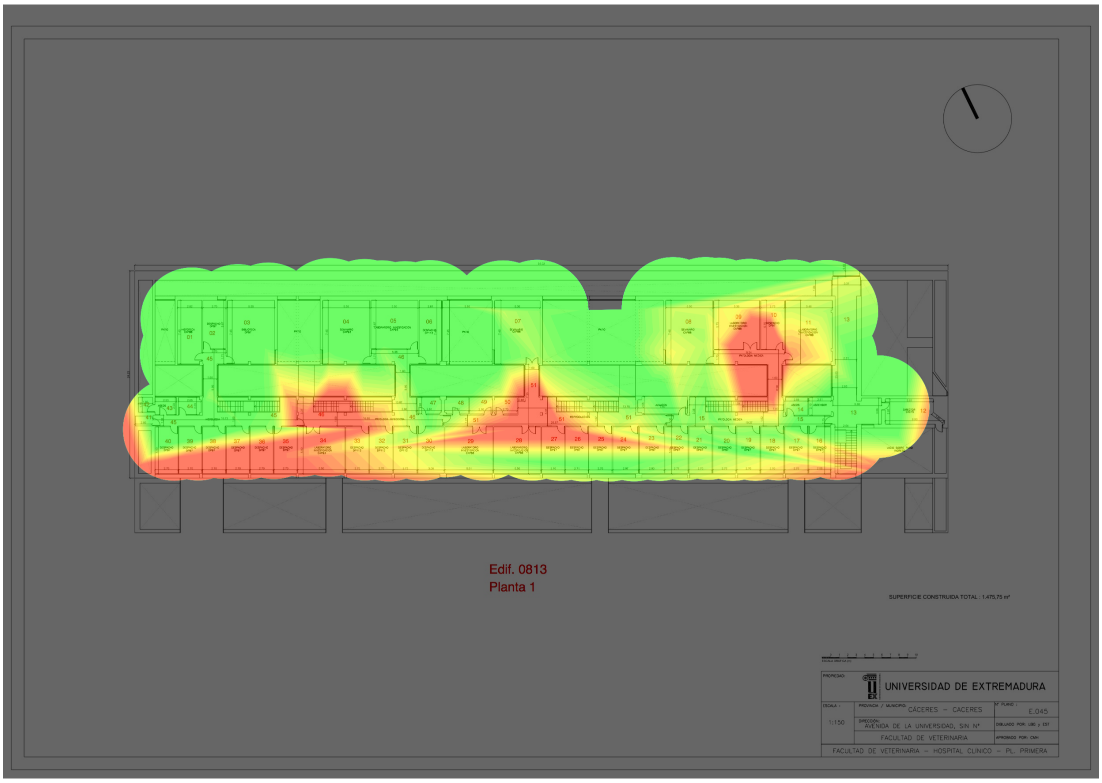
In the illustration we can see that the coverage in the case of 2.4 GHz is broader, as it was expected; and that in the rest of the areas both frequencies overlap.

We can also see that coverage is not reached in some areas, but it happens in the surfaces mentioned before, which are not essential.

4.15.72. Building 0813 Floor 1

4.15.72.1. Signal to Noise Ratio

In the picture below we can clearly see the areas in which a priori bad signal reception exists, and where the quality with which we perceive it is high.

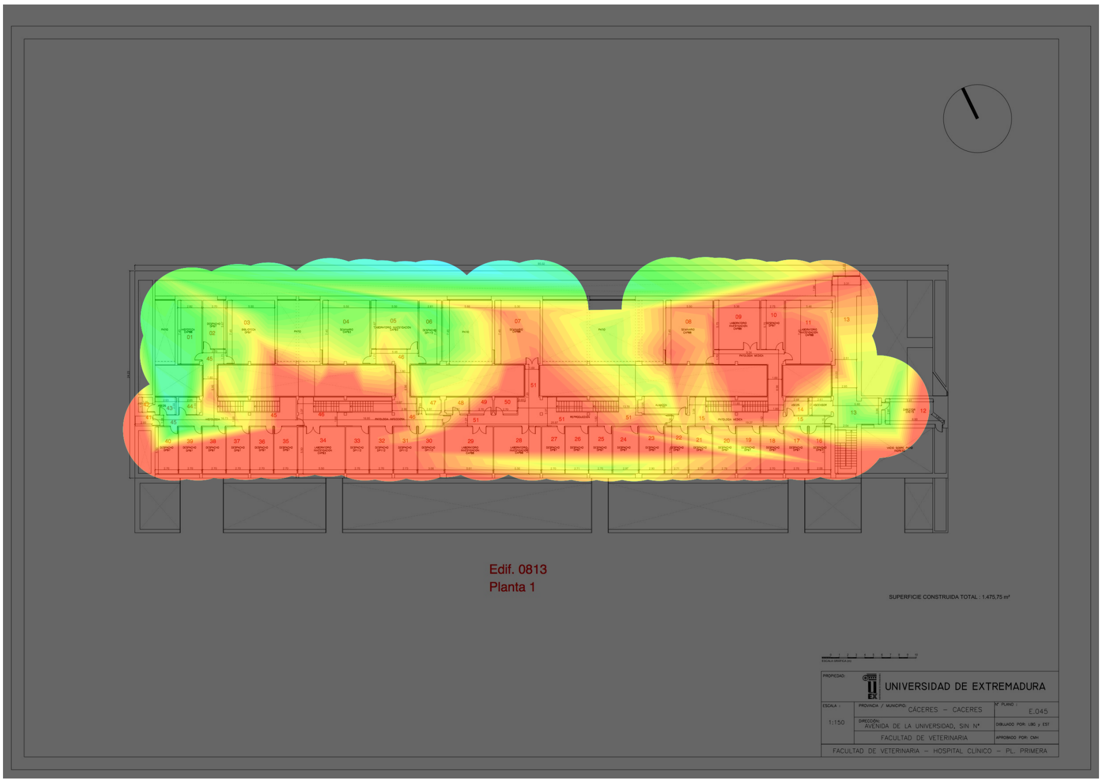


It can be seen that the areas where the classrooms are covered with a good quality signal, while some corridors, the yard or the office areas have less coverage. That is because they are not considered priority areas, but transit areas that sometimes have a lack of facilities. In the case of the offices, teachers have a wired connection to have access to the Internet.

The reference values used were:

- At a mínimum value 10 dB.
- Maximum value of 45 dB.

4.15.72.2. Signal Level



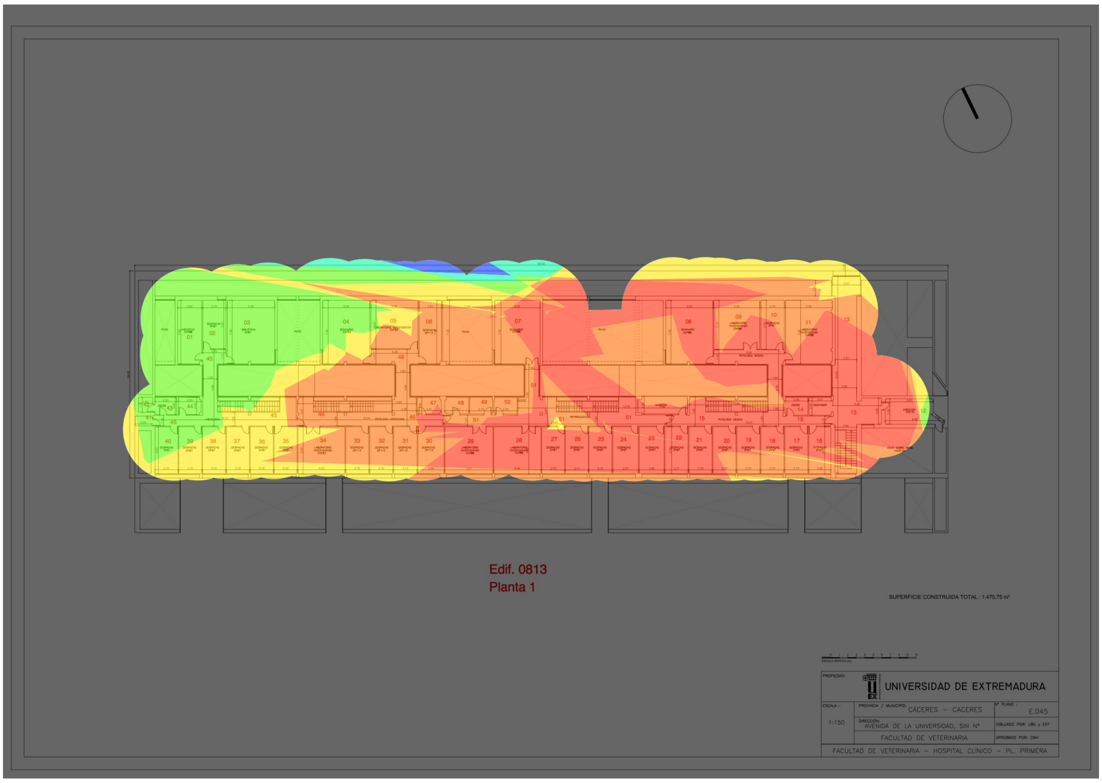
In this picture we can see again how the signal level in the areas of the classrooms are covered with a good intensity, while some corridors, the yard or the office areas have a lower intensity.

We can observe that the results are very similar. However, the way in which the noise affects to the signal, makes the signal captured to be much lower than it would be received if there were no noise.

The reference values used were:

- At a mínimum value -90 dBm.
- Maximum value of -55 dBm.

4.15.72.3. Number of Access Points

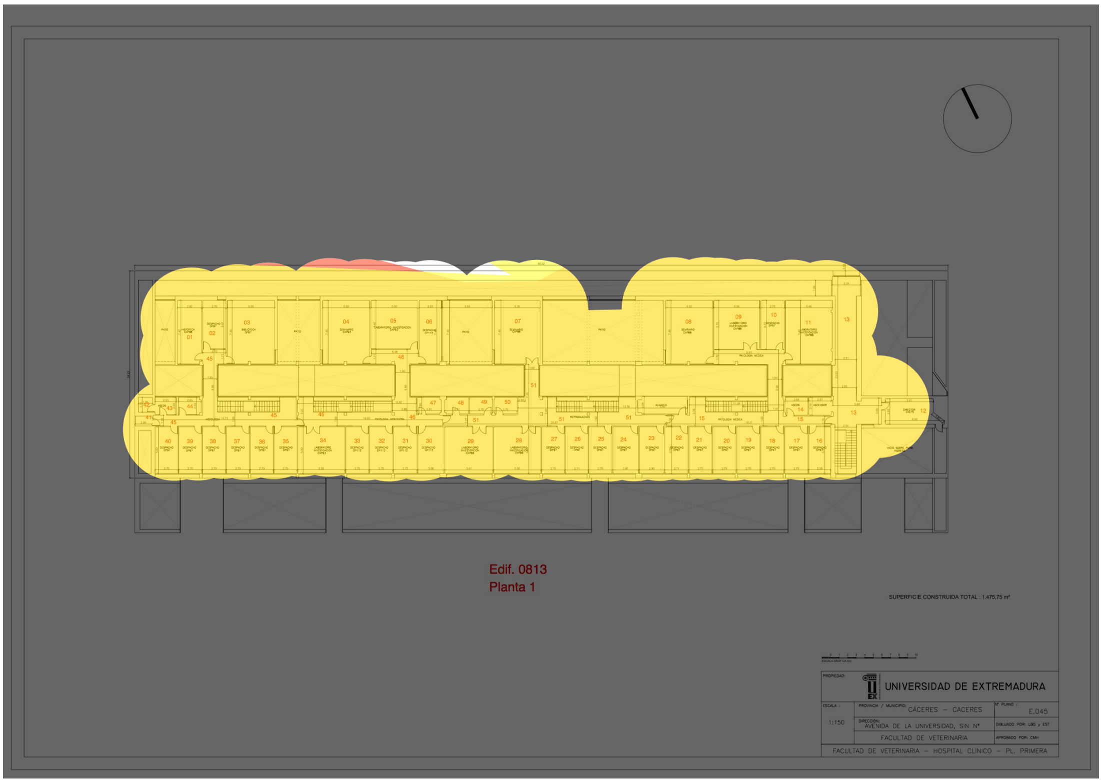


In the picture above we can see the number of access points to which we have a connection option on the surface of the floor.

Again, we can see that the areas where classes are given have access to a larger number of networks, while in corridors or transit areas there is no access to them.

The minimum value taken to consider that you could connect to an access point was -80 dBm.

4.15.72.4. Coverage per Frequency Band



In the illustration we can see as equal coverage in both frequencies. This is because the surface of the building is small and it perfectly comes out a 5GHz frequency.

5. CONCLUSIONES

5. CONCLUSIONS

After taking into consideration all what has been mentioned, we have achieved the following conclusions:

The results obtained from the software were satisfactory, and they correspond with the initial values that were assumed for the network. So, we believe that the methodology and the tools employed have been the proper ones.

In the same way, we have noticed that the bigger the distance from the access point, the more reduced the SNR values are. For this reason we have concluded that there was more attenuation when the distance was bigger.

Generally, the classrooms had an access point or, at least, they had an access point near them that provided the area with a good quality signal.

Furthermore, we have identified different shadow zones, and it has been demonstrated their deficient signal. These conflictive areas generally were storages or other places where connection was not necessary but, at some particular cases, there were common zones. Besides, it was also noticed that at some places, for instance at the offices of the faculty, in which the range of the wireless network was not enough although a fixed connection was available.

The information content in the project will be employed to change or install new access points in order to be able to provide a service of quality everywhere; that is to say, at all places of academic interest in the University of Extremadura.

As the most outstanding conclusion of the research carried out, we can assure that exists an excellent coverage in almost all the places where wireless connection may be needed. Besides, with all the data obtained the network will be improved in order to ensure a service of quality.

Finally, the NetSpot software offered a great amount of additional information such as the possibility to measure the speed of network, the channels where the connection took place and other parameters. We choose for the research and we show the information that we consider most relevant and interesting to work properly of the WIFI network.

CONCLUSIONES

De todo lo expuesto anteriormente hemos obtenido las siguientes conclusiones:

Los resultados obtenidos mediante el software fueron satisfactorios, y se corresponden con los valores que inicialmente se presuponían para la red, por tanto, creemos que la metodología y la herramienta utilizada han sido las correctas.

Igualmente hemos podido observar que a mayor distancia del punto de acceso, los valores de SNR se veían reducidos y por tanto, concluir que existía una atenuación según la distancia era mayor.

Generalmente todas las zonas habilitadas para clases como son las aulas estaban dotadas con un punto de acceso, o tenían una buena cobertura de la señal por un punto cercano.

Asimismo se han identificado diferentes zonas de sombra, donde se ha comprobado la deficiente señal de la que se disponía. En la mayoría de los casos estas zonas fueron almacenes u otros espacios sin necesidad de conexión, pero en algunos casos puntuales eran zonas comunes. También se observo en algunas zonas, como en los despachos de alguna facultad, en las que el alcance de la red inalámbrica era insuficiente, que en el interior se disponía de una conexión fija.

La información contenida en el proyecto se utilizará para reubicar o instalar nuevos puntos, para poder suministrar un servicio de calidad en la totalidad de los espacios de interés académico de la Universidad de Extremadura.

Como principal conclusión del estudio llevado a cabo, podemos afirmar que existe muy buena cobertura en casi todos los espacios en los que se podía necesitar la conexión a una red inalámbrica, y que con los datos obtenidos se podrá mejorar más, para garantizar un servicio de calidad.

Por último, el software NetSpot nos daba mucha información adicional como la posibilidad de medir la velocidad de la red, los canales en los que se realizaba la conexión y de otros parámetros. Elegimos para el estudio y mostramos la información que consideramos más importante e interesante para el correcto funcionamiento de la red Wi-Fi.

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7. ANEXOS

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Debido a la gran cantidad y extensión de los documentos para ser adjuntados a continuación, serán incluidos como archivos independientes para acceder a los diferentes informes en formato PDF y los archivos en formato .netspd de la totalidad de las zonas estudiadas, donde se pueden observar los valores exactos de cada punto de medida, u obtener algún dato más si fuese necesario.

A continuación se muestra un pequeño índice con la nomenclatura de los archivos y su correspondencia con los centros del campus.

Centro	Nombre del archivo
Facultad de Derecho	DER.netspd
Escuela Politécnica	POL.netspd
Biblioteca Central	BIB.netspd
Facultad de Ciencias del Deporte	DEP.netspd
Facultad de Enfermería y Terapia Ocupacional	ENF.netspd
Facultad de Estudios Empresariales y Turismo	EYT.netspd
Facultad de Filosofía y Letras	FYL.netspd
Palacio de la Generala	GEN.netspd
Instituto de Lenguas Modernas	ILM.netspd
Edificio de Usos Múltiples	MUL.netspd
Facultad de Formación del Profesorado	PRF.netspd
Rectorado Cáceres	REC.netspd
Servicio de Actividad Física y Deporte	SFD.netspd
Servicio de Gestión y Transferencia de Resultados de la Investigación (SGTRI)	SGT.netspd
Facultad de Veterinaria y Hospital Clínico Veterinario	VET.netspd