RF Propagation: A Study of WiFi Design for the Department of Veterans Affairs

A White Paper

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Introduction

Radio Frequency (RF) Propagation is the study of how radio waves broadcast over great distances. Simply put, RF signals affect our daily lives in more ways than the average person can count. From cell phones to TV signals, from a garage door opener to ID readers, and from WiFi antennas to the original transistor radio – all of them rely on a radio signal to be sent by one device, and received by another. These signals contain differing amounts of information. Some devices respond to the composition of the wave itself – frequency, modulation, etc.

Others depend on the information carried by the signal – data packets for a cell phone signal and broadcast information for a television program. Depending on the signal’s transmit power, an RF signal can have a modest range of several inches (an ID badge) or travel for miles (microwave transmissions). Most signals are harmless, but some can be very dangerous.

This paper will discuss how these signals are sent and received in a VA hospital environment, and the transmission implications for different applications. By the end, it should be clear how factors can negatively impact a signal’s transmission (Path Loss), and how these limitations can directly affect wireless design requirements.

Transmission and Reception

A typical RF signal is very similar to light – it goes out where it can, and will continue to travel until it is deterred. Like a beam of light, a radio signal can be focused to travel more effectively in a particular direction, or it can be broadcast in an omni-directional fashion going in all directions at once.

It is important to understand the relationship between the transmission and reception of a signal. A typical car radio is able to receive the signal from an antenna that may be 100 miles away, but would never have the strength to push a signal back to that antenna.

Therefore, RF design must keep in mind the relationship between the antenna and the receiving device – will it be a one-way relationship, or a two-way street. A WiFi antenna could be installed within the middle of a facility, and wireless clients could receive its signal, but without the ability to successfully send data back on the uplink channel, the solution would limit the effectiveness of this wireless deployment.
Even if the client was able to increase its transmit level to get the signal back to the Access Point (AP), the network designer needs to remember that it will most likely not be the only device on this network or in this facility. If all the devices had to transmit at their highest power settings just to upload data, this would create too much interference to have an effective system.

These are important design criteria that need to be taken into consideration for an indoor wireless solution. Below is a chart that examines the relationship between signal strength as a factor of Received Signal Strength Indicator (RSSI measured in dBm) and distance.

**RF Impediments**

The path that an RF signal travels is very important to the strength of that signal when it is received by the client.

Similar to a beam of light, an RF signal can bend around corners and can reflect off of surfaces. Imagine a light that is shone down a hall-
way – its light is even able to shine around corners, depending on how far away from the source they are. The same holds true for RF signals.

Line of Sight is very important in maintaining signal strength and accuracy. The loss on a signal as a result of going around a corner is typically minimal. It is commonly referred to as Knife Edge Diffraction, and doesn’t usually affect signal strength in an indoor environment.

An RF signal can also reflect off of a surface, similar to a beam of light. While this isn’t typically used as a design factor, it can help to extend a signal in some instances.

One very important detriment to RF propagation is interference. Interference occurs when two similar signals arrive at the client at the same time. This can happen for a number of reasons. If two signals on adjacent frequencies arrive at a client, this may cause a particular type of interference. If two signals on the same frequency or channel arrive at the same time, co-channel interference could be the result.

As an example, imagine that you are in your car at a stop light, and you briefly lose your radio signal. However, if you pull up just a couple of feet, you get it back.

This occurs because the signal is reaching the car’s antenna directly, and a reflection of that same signal could be bouncing off of a nearby building or truck, arriving just a few milliseconds later, and causing the interference.

This is known as Raleigh or Fast Fading. Going back to the indoor model, a client in a large lobby (as an example) could get a number of signals from various diffracted sources.

The resulting “multi-path” of the signal could cause varying levels of interference resulting in anything from a slight disturbance to a full dead spot. It is important for the network design engineer to understand how the path of a signal may be affected by the facility, and how that could impact the end user experience.

Radio signals and clients do not always find themselves within line of sight. The majority of signals must pass through doors, walls, equipment, and even people. The signal is weakened – even if only slightly – after passing through an opaque object.

Therefore, wireless network designs must take these impediments into account when determining the signal’s path.

How far these signals will cover is measured generically by the coverage density of an AP – square feet per access point. The amount of
loss on the signal as it passes through different types of materials is measured as the loss on the signal along the path, or as “Path Loss”.

Below is a chart that illustrates how different construction standards within a typical VA facility can adversely impact an RF signal:

Below is a guide to the columns from the table:

<table>
<thead>
<tr>
<th>Material</th>
<th>Distance in Meter (2.4G &amp; 5.2G)</th>
<th>dB Attenuation due to Material</th>
<th>Coverage Area in Sq Ft</th>
<th>Percentage of Free Air Coverage Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free air</td>
<td>10</td>
<td>0</td>
<td>2,826</td>
<td>100%</td>
</tr>
<tr>
<td>Glass window</td>
<td>8</td>
<td>2</td>
<td>1,809</td>
<td>64%</td>
</tr>
<tr>
<td>Drywall, wood door</td>
<td>6.7</td>
<td>3.5</td>
<td>1,269</td>
<td>45%</td>
</tr>
<tr>
<td>Cubical wall, cinder block</td>
<td>6.3</td>
<td>4</td>
<td>1,122</td>
<td>40%</td>
</tr>
<tr>
<td>Metal door, glass wall</td>
<td>5</td>
<td>6</td>
<td>707</td>
<td>25%</td>
</tr>
<tr>
<td>Brick wall</td>
<td>4</td>
<td>8</td>
<td>452</td>
<td>16%</td>
</tr>
<tr>
<td>Coated glass</td>
<td>2.82</td>
<td>11</td>
<td>225</td>
<td>8%</td>
</tr>
<tr>
<td>Fire exit door, concrete wall</td>
<td>2</td>
<td>14</td>
<td>113</td>
<td>4%</td>
</tr>
<tr>
<td>Concrete wall with mesh</td>
<td>1.12</td>
<td>19</td>
<td>35</td>
<td>1%</td>
</tr>
</tbody>
</table>

- **Distance in Meter (2.4 G & 5.2G)**. This defines how far an RF signal would travel at the respective frequency values after impeded by the different construction materials. Ten meters of free air propagation is used as the signal attenuation baseline. A glass window does little to impede the signal, while coated glass is almost as bad as concrete.

- **dB Attenuation due to Material**. dB is the value used to measure the signal strength of an RF signal. Each of the construction materials listed above causes the signal to lose strength when passing through, but some are dramatically denser than others.

- **Coverage Area in Sq Ft**. Quite simply, how much area would a signal cover in free air after it has passed through a layer of construction material.

- **Percentage of Free Air Coverage Area**. Compared with the 10 meter radius free air coverage base line, this is the percentage of coverage area after the signal has passed through the construction material. Notice that a glass window allows 64% coverage area, whereas coated glass only allows 8%.

By themselves, these are very telling indicators of how a typical RF signal can be lost in buildings of differing construction.
However, alone in the chart above, they don’t take into account their combined impact when two or more are used on a particular floor of a hospital or outlying building.

**Definition of VA Program Coverage Values**

An important component of wireless coverage is the level of coverage that designed to exist in a particular area. For the current VA program, Catapult is contracted to provide “location-based coverage” throughout the entire facilities.

But the level to which a client can be located depends on the type of coverage density that is used. If there is one AP in a building, and a client connects to that AP, it can be said that the location of that AP is known.

Of course, this is not the whole story, so another factor must be added to the equation – the accuracy of the location. In the example cited above, the accuracy of the location in that building is only helpful if the building is extremely small.

The larger the building, the poorer the accuracy determination will be. Therefore, a second AP will be added when the building is large enough – not just to add increased signal availability, but to introduce the idea of location accuracy using triangulation.

When the construction standards of a building are known, a determination of the distance from the AP can be made, but without a second reading, no indication of direction can be made with just one AP. It is based on this idea the VA WiFi program has defined three separate coverage scenarios to use on this program.

**Limited Coverage Model**

The first coverage model is Limited. As the name would imply, this coverage model does not provide a comprehensive design footprint. The idea is that APs would only be used in key areas of a building to provide coverage.

Access points will only cover a finite area, and there will not be much overlap between these AP footprints. A client, therefore, will only typically see only one AP at a time.

This is an ideal solution in buildings or areas like boiler plants, electrical/mechanical areas, or other areas where WiFi users do not typically
spend large amounts of time.

The benefit of this solution is that it saves on the costs of additional APs since it only covers those areas within an area that have the need.

These types of facilities typically have high levels of electromagnetic interfere from machinery, high levels of path loss from unfavorable construction standards, and few permanent occupants to be affected on an ongoing basis.

The downside of this coverage model is that there is no redundancy – when an AP goes down, there’s no coverage slack. So this model must be chosen carefully and with some thought to the end-result.

**Standard Coverage Model**

The next coverage model is Standard. With this model, coverage redundancy is introduced in the building or area providing what is also sometimes called “voice grade” coverage. For every point within the coverage area, a client will be able to see a minimum of two APs at one time.

Typically, there is a coverage threshold that a signal must achieve when reaching the clients – a level to be determined by the facility manager and design engineer.

The voice capability of the system is guaranteed. Data transmissions don’t need a coverage model that is as complete since they are able to resend data packets for any erroneous transmissions. Voice transmissions are less forgiving because there is no ability to resend the lost information.

It is the redundancy of signal strength that ensures the signal is correctly received by the client.

This is also an important coverage model because location accuracy for a client is greatly increased.

A client not only registers on both APs, but the geographic area within the facility where that is possible is easily definable. Using RSSI readings from the APs, the system makes its best guess as to where the client is.

The typical accuracy for this type of location tracking is somewhere between 10 to 40 meters.
Below is a graph that illustrates how the signal overlap between two APs can help to locate a client within a facility.

**Enhanced Coverage Model**

The last coverage model is Enhanced. With this model, coverage is guaranteed by at least three APs at any point. This is by far the most comprehensive coverage model, but also the most expensive. The main benefit and reason to deploy a solution like this is to ensure triangulation for the location based services to be used by such applications as Radio Frequency Identification (RFID).

Triangulation is determined by one of two methods: RSSI measurements or Multilateration. Similar to the Standard coverage model, measuring RSSI for this model will provide the location of the client in the facility.

By adding the third AP to the client’s coverage radius, the level accuracy increases dramatically. Multilateration is the determination of a client’s position using the time difference of arrival (TDOA) of a signal sent from the client to the three APs. By measuring the distances from the client to the APs, the Enhanced model calculates a client’s position to an average radius of 3 to 10 meters.

Because of the signal requirements to accurately determine distance, this coverage model is the most susceptible to impediments of RF signal through a building.
A loss of 8dB when a signal passes through a brick wall will directly impact the ability to determine location. Therefore, a greater density of APs is required throughout the facility to ensure the proper/required coverage thresholds are met.

Below is a diagram that graphically illustrates how the APs interact with the client, measuring the strength or time of arrival to determine the client's location.

There are strategies to deploy a cost effective wireless network with location based capabilities. The site team should first identify those areas that don’t need coverage at all – they should be removed from the requirements, and therefore remove unnecessary costs.

Next, the site team should identify those areas that don't have employees sitting in them on a regular basis – boiler rooms, mechanical rooms, and other areas that may potentially be used for storage.

Unless a future RFID or wireless VoIP solution will be used in there, they should not be designed for anything more than Limited coverage. After that, the site team will need to decide whether they will have a facility-wide solution with Standard everywhere, and use Enhanced for special areas, or design a system using Enhanced coverage as the baseline with Standard only in those areas that are specifically identified.
The latter is generally more expensive, and is the reason that the site team and executive sponsors need to understand the cost implications.

Surveying to one coverage value doesn’t necessarily give an indication of what the others will require for their coverage. That is to say, needing 10 APs to cover an area using Limited doesn’t immediately mean that 20 would be needed for Standard, or that 30 would be needed for Enhanced coverage.

And the reverse is true as well. The areas would need to be re-surveyed at the new coverage standard, and a new design would need to be calculated.

As an example, designing a system utilizing multilateration requires a lot of data points providing information on the RF impediments in the facility. That same level of information wouldn’t necessarily be collected if the facility were surveyed to Limited where signal overlap isn’t a consideration.

**WiFi Design and Validation Process**

In order to properly understand the requirements for a site, and how best to design an Enhanced solution throughout a facility, there are a lot of steps that must be followed. Every site will be designed and deployed to the same wireless standards, even though they were not built to similar construction standards.

The process will include surveys and design stages to evaluate site factors, and their predicted impact to the completed system.

An initial site survey is the first stage of a site’s deployment, and the most critical. Combined with an analysis of the floor plans, it is the initial survey that uncovers a site’s design challenges and RF shortcomings, and addresses them head on.

A test transmitter is placed in potential locations for APs, and data points are taken to report on the predicted wireless coverage for that AP location.

The data is tabulated after all of the surveys have been completed, and the resulting design is delivered in a Design & Engineering package (D&E) which will include schematics showing the optimal architecture.
The capture of survey data is essential in order to transform site information (i.e., network architecture, RF propagation) into practical site designs for the deployment. Walk-through site surveys are necessary and cannot be replaced by survey-based algorithms in a simulated modeling tool.

There are a number of industry tools that allow engineers to import building and site blue prints and define characteristics like the density and composition of walls.

These are helpful tools, but they are not a substitute for a walk-through site survey when architecting a solution of this size and complexity. Catapult, therefore, “walks” every floor of every building within the VA facilities that will be covered by the completed system.

An important requirement for this phase of the deployment is that if an area of the facility is not surveyed, it will not be designed or covered by the WiFi system. That is the only way to guarantee the coverage will meet the stringent standards.

The main focus of the walk-throughs is to utilize a transmitter to simulate AP positioning, and determine what coverage would look like.

While this can be time consuming in buildings with unwelcoming RF construction, it is invaluable in the determination of how many antennas need to be deployed, and where they need to be located.

A transmitter is placed in a room or hallway, and turned on to simulate a standard AP. The engineers then walk into and out of every nearby room measuring the coverage.

Once completed in that location, the transmitter is powered down, and moved to the next location – either down the hall or on the next floor.

By utilizing this method, the engineers are able to investigate RF overlap from multiple APs in one location – a crucial component of the location-based coverage we are offering. It is also this room-by-room approach that allows us to find those problems that might otherwise go undiscovered.

As an example, one site had walls so thick that when a transmitter was placed in a room, and the door was closed, there was no coverage in the hallway outside. Another location was literally built with its basement as a bomb shelter, and therefore required APs to be placed in the bathrooms to meet the coverage requirements.
These are situations that a modeling program won’t be able to predict based on a floor plan.

Once the data has been collected, a team of wireless engineers analyzes the data for site patterns – building construction, outside interference, etc. This information is used, along with the raw data collected during the site walk to put together an RF design. How many APs will be needed? What server configuration will be used as a result? Where will the APS be placed for maximum coverage and efficiency? What telephony closets will they run back to?

These and many more questions are addressed in order to come up with the best network design.

One challenge that has come up during this deployment is how to meet the LBS component of the contract within distinctly older buildings.

Some facilities don’t have sheet rock between rooms, but rather use poured concrete or concrete brick with a steel-reinforced infrastructure. One site in particular was built with an adobe (dried clay) infrastructure to mimic the natural surroundings of the area.

While these standards may have been the norm in the decade when these buildings were constructed, or may be a popular choice considering the geographic region, they wreak havoc on RF propagation.

It is crucial that the survey data provides a complete picture so that the design package can account for these and other challenges. Once completed, the site design package is presented to the VA teams (site, regional, and PMO) for review and acceptance.

The RF environment is infinitely complex and constantly changing. Changes in RF interference and RF interactions such as reflection, refraction, and scattering within an indoor environment can lead to differences between the planned and actual RF coverage.

For these reasons, after the installation of the wireless LAN is completed, there is a post-deployment verification process performed in order to measure and optimize the actual wireless LAN accuracy.

Again, engineers walk through the entire facility, and verify that coverage and handovers occur as designed. AP placements are confirmed, interference is measured again, and all of this is recorded for the final As-Built document.
During this process it may be necessary to modify access point radio settings (i.e., radio transmitter power, channel selection, data rates) and/or locations to address any problem areas.

**Once You’ve Seen One VA...**

The original VA contract referenced that Albuquerque had a square footage range of 80,001 to 82,500. The actual square footage was 943,000 sq ft, and there was no reference of the adobe construction built over a steel mesh cage between rooms.

The contract didn’t reference that VACO’s three lower levels (basement) were literally built to be a bomb shelter, using extra-thick steel-reinforced concrete. For Dallas, the contract listed “more than 15 buildings,” but that didn’t even come close to the over 50 buildings located at the facility.

The main facility at Togus, ME was originally built in 1869, whereas the average age of a facility on this contract is over 50 years old. The “newest” facilities so far were built in the 1970s.

The adage of “Once you’ve seen one VA, you’ve seen one VA” has never held truer than on this program. The information for the different sites concerning their construction standards referenced “brick” and “concrete”, but neglected key factors like the age of the facility and other mitigating factors.

**Conclusion**

This paper has shown how numerous factors can impact a wireless design – from the very walls to how the APs are configured and placed in the facility.

Most types of construction have an impact on an RF signal as it passes through them, and site surveys look to identify the loss of the signal and compensate for it with additional access points.

The requirements for location based services have a direct impact on the density of APs throughout the buildings, and the types of services that will be run on the wireless system drive the requirements for AP placement and utilization.

This paper has illustrated how RF propagation works, and Catapult’s process for the design and deployment of access points in a wireless network:
1. Identify the requirements for the system.
2. Assess the construction factors that may impact the design.
3. Survey the facility, and build a site plan.
4. Deploy the system, and validate that the results match the predicted results.

This follows industry standards for wireless deployments, and Catapult’s continued methodology for delivering successful wireless solutions.

For more information about Catapult’s wireless capabilities:
- Call 240-482-2100
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