Practical Warehouse Wireless Design: An Experience-Based Guide

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Introduction

Warehouses can be extremely challenging environments for which a wireless professional must create a design. Warehouse layouts can range from high ceilings with open stacking and staging areas, to congested spaces with floor to ceiling racks or closed in picking modules. Client devices are often outdated and new devices have been slow to evolve with the changing technology. Temperatures can vary dramatically from high heat in the summer to cold in the winter, not to mention the use of wireless in coolers, refrigerators, and freezers. Traffic on the warehouse floor can be hazardous with higher speed vehicles such as forklifts, pickers, tow trackers, and even robots. And let's not forget the biggest challenge, everything is always changing. Inventory is always being added to or pulled from racks, pallets being offloaded from trucks and stacked, and sometimes racks get moved or new equipment installed. With all these challenges and dynamic variables, it's incredible that wireless works in warehouses at all, particularly when not implemented with effective design techniques.

As warehouses get larger and more advanced, so do their wireless requirements. Wireless is no longer a luxury in a warehouse, it's a mission-critical system and is only getting more complex. The RF requirements have become stricter to support features like RTLS solutions for tracking of assets, people, and even robots, and seamless client roaming for devices mounted on vehicles.

Early wireless designs were generally based on a coverage model where the main concern was, "Do I see a good signal level everywhere?" As network requirements increased and became more advanced, it didn't take long to realize that good signal levels did not mean good quality signal, or that the needed capacity existed. Many warehouses designed today still fall victim to this same coverage design model. "Can I see good signal levels in between the racks?" And what we learned in other types of wireless deployments is still true in warehouses, good signal levels do not mean good quality signal or available capacity. Warehouse design requirements have gone from a simple coverage model to complex RF design models that provide the needed coverage and capacity.

What is so Different About a Warehouse?

When creating a warehouse design there are many things that you may or may not have to consider outside of the normal wireless design considerations, all of which can have a major impact on the design and the performance of the network. Here are some examples.

- What kind of devices will be supported? This is important for all wireless designs, but warehouse clients can be even more challenging.

- Will client devices be mounted or used on vehicles?
- What is the ceiling height?
- Are there racks, or is it all open stacking area?
- If there are racks, what are their dimensions? And how close together are they?
- Are the racks ever moved or are they stationary?
- Are there any picking modules? How many levels do they have? And what are they made out of?
- Is coverage required at multiple heights or just at floor level?
- What kind of inventory do the racks hold?
- Do the inventory levels fluctuate? If so, how often? And by how much?
- Is the warehouse climate controlled?
- Are there coolers, refrigerators, or freezers? And is coverage required in these areas?
- Are there any mounting restrictions?
- Where are the Intermediate Distribution Frames (IDFs) located?
- Do they store any hazardous materials which may require special enclosures, equipment, or training and Personal Protective Equipment (PPE)?

The answers to these questions are what make a warehouse design so different from a standard enterprise wireless design. They illustrate some of the challenges you'll have to design around, and how the environment is always changing, even more so than normal. This information is the key to creating a successful wireless design for a warehouse, because if you can identify the challenges and the source of what is changing upfront, you can minimize their effect on your design. Let's look at some of these questions and factors to better understand their impact on a wireless design.

Devices to be Supported

As with any wireless design it is important to understand what type of devices will need to be supported and their capabilities, requirements, and quantities.

I was once told that the equation for wireless performance was based 50% on the network, and 100% on the client. When I pointed out that the total was over 100%, I was told "Yup, because a poor performing client can ruin the simplest equation, and that the network is nothing without a client." The key to wireless performance is far too often focused only on the network, when in reality wireless performance is created by designing a client and network combinations that are well matched and perform well together. When designing a wireless network, performance and stability will be impacted by your weakest link, which will normally be the client devices, and in warehouses this is especially true.

The clients used in warehouses are often older devices, and even some of the newer model clients have been slow to keep up with the advancements in Wi-Fi technology. They are often

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SISO (Single In Single Out) devices that don't perform well in high multipath environments. Battery life is quite often the biggest focus and extending battery life can sometimes sacrifice performance.

Companies are also more likely to upgrade their wireless infrastructure before they upgrade the clients they are currently using; I consider this to be like paving a new road and expecting it to improve the performance of your old VW bug. So, it is critical that you understand the client devices and their capabilities so you can design for them.

Some things to consider about warehouse clients when designing a wireless network:

- Is the customer upgrading their current clients to match the new wireless infrastructure?
- Are you supporting a mix of older clients and new clients?
- Are you designing for 2.4 GHz or 5 GHz? Or both?
- What data rates need to be supported for the clients?
- What kind of battery life do the clients have? Will any kind of power save be enabled?
- Does the client reduce its capabilities when the battery charge gets low?
- What are the roaming characteristics of the clients?
- What firmware version are the client devices running?

These are only a few examples of things to understand about warehouse client devices. The more you know about the client devices to be supported the better you can design to support them.

Vehicle Mounted Devices

Warehouses have become a regular interstate with different types of vehicles racing back and forth and performing various tasks. Some of them even have marked off roadways and traffic signs now. All of this is to optimize the workflow and to get things done faster. Many of these vehicles are equipped with truck mounted computers and devices. These devices are used for many things from scanning inventory, to tracking assets and safety monitoring. So why does this create a design concern? Several reasons.

First is interference. The mounting location of many of these devices, especially if they are using a built-in antenna, can affect the received and transmitted signals. Thick metal protective cages will block signal, and protective fencing can create scatter, which will significantly impact the signal quality and performance of the client. *Figure 1* shows a truck mounted device from a typical warehouse deployment. If this device was using the built-in antenna the signal might have had to get past the metal roof and protective cage, or the mesh fencing behind it, and then the protective case the device is mounted in, all while moving quickly through the warehouse. Fortunately, this set up was using an external antenna, mounted outside of the driver's protected area, giving it better line of sight to the access points, but this is not always the case.

FIGURE 1

Roaming is another concern. Warehouse vehicles move quickly through the environment, and the devices mounted to them need to be able to maintain a stable seamless connection. The design, configuration, and RF environment need to be optimized to meet the roaming requirements of these types of devices, taking into account where they are mounted and how fast will they be moving.

Some things to consider when it comes to roaming:

- What type of security is configured?
- What data rates need to be supported?
- Do all devices being supported have similar roaming requirements?

Vehicle mounted devices are a very important consideration and how they are mounted and used can definitely have an impact on the design and recommendations you suggest to help make the project successful.

Ceiling Height

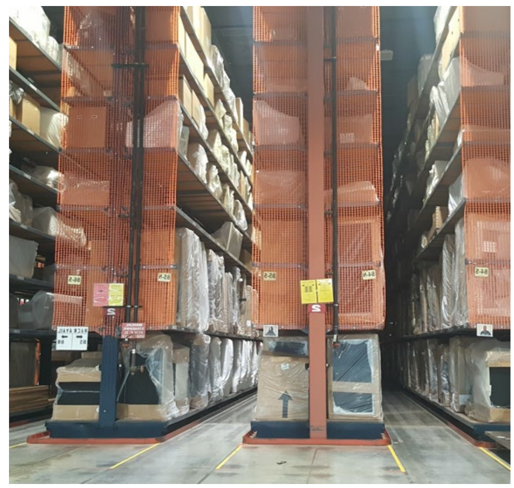
Far too often I come across warehouses with 50′ ceiling that have access points with internal omni-directional antennas connected to them, this is like nails on a chalkboard to me. Correct antenna choice and placement is critical in creating a warehouse design, especially when dealing with high ceilings.

Access Points with internal omni-directional antennas have an optimal mounting height of between 8 to 20 feet. Above this the signal propagation will be more across the ceiling than down on the floor where it is needed. When dealing with high ceilings I recommend the use of directional antennas positioned to focus the signal down the aisle or mounted to the ceiling aimed straight down instead of across the ceiling and avoid creating RF pollution.

Ceiling height is an especially important data point in the RF design. It needs to be factored in when choosing the access point model to be used, antenna types, and mounting locations. You also must consider ceiling height when you're calculating cable run lengths, installation cost, and future repair costs if you have to replace an access point.

Racks

Racks can be some of the most challenging obstacles in a warehouse for a wireless professional to design around. They can come in all different sizes and layouts and are made from different types of materials like plastic, wood and metal. They can be filled with anything from paper products, which offer little attenuations, to liquids which can block signal totally.



Warehouse rack layouts vary dramatically. Spacing can go from very close together to spread out and open, and spacing is not always standardized within a warehouse, it can change from aisle to aisle. The number of shelves per rack can vary, the depth and length of the shelves can vary, and the direction in which they are oriented can be different. This all has a significant effect on the design approach and type of equipment used.

One of the hardest things about providing signal in between rack is how to cover the aisle, the space between the racks, without over-saturating the RF environment. One method of covering these areas is to shoot signal in from the edge using directional antennas. A 35 – 60-degree beam width antenna is a good starting point and setting the antenna back away from the rack a minimum of 20’ will give better penetration into the neighboring aisle. Alternating ends in a saw-tooth pattern and skipping about 4 aisles between antennas on the same side will generally provide good edge coverage into the aisles without over-saturating the environment, but this will not usually cover all the aisles. On average, with the antenna centered on an aisle, it will cover that aisle and about a third of the aisle on either side of it, depending on the length of the aisle and the inventory stored in the racks. This will leave a zig zag pattern of weak signal down the center of the rack which can be covered from above using directional antennas focused down from the ceiling. I try to provide an access point per aisle or every other aisle, either overhead or shooting in from the edge. This keeps the best line of sight and limits the amount of signal that must pass through inventory.

Figure 2 shows a very large warehouse design using directional antennas drop mounted from the ceiling focusing signal down the aisles, and overhead access points with directional antennas focusing signal down. Though it is hard to see in the picture, the width of the aisle at this location goes from very close together to double-wide. The change in aisle width will change the density of access points needed.

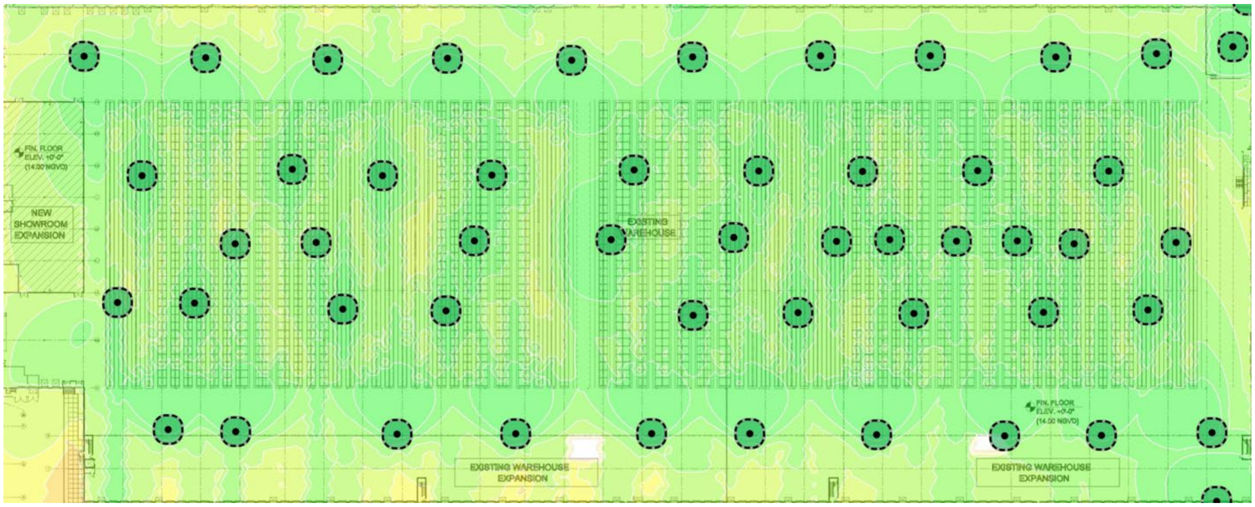


FIGURE 2

This is only one way of approaching a design for these types of areas and may not be the best depending on available mounting locations, ceiling height or rack design.

Picking Module

A picking Module is a structure built for pulling inventory to fulfill orders in a warehouse. They usually have multiple floors and have shelves or racks built into them, see *Figure 3*. These are often closed in structures with metal floors, ceilings and walls, which can create an RF nightmare. The signal in these units can be affected by reflection, scatter, and even waveguide effect. They are areas with high amounts of multipath which can create performance issues for many warehouse clients.

FIGURE 3

- **Reflection** – When a signal reflects off of a smooth object and its path is redirected. The angle at which the signal is reflected is equal to the angle at which the signal approaches the object.
- **Scatter** – When a signal is reflected off of a rough object, or an object that is smaller than the wavelength of the signal. This causes the signal to be reflected, or scattered, in multiple directions, degrading the signal quality and often making it completely unusable.
- **Waveguide Effect** – Microwave communications have used waveguide to direct signal for years. A waveguide is a

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hollow tube made of metal designed to contain and direct signal to and from transmitters and receivers.

You hear a lot about reflection, scatter, and other things that affect wireless signal, but not too much is mentioned about wave guide effect, and how it can impact a wireless network. A common place this can be seen is when an access point is mounted too close to a heating or air conditioning vent. The signal can be transmitted into the vent and the ductwork will act as a wave guide carrying it to other parts of the building. This can create a problem similar to hidden node. Some picking modules, due to their construction, can act in a very similar way as a wave guide, *Figure 4*. Understanding how signal will propagate through a structure like a picking module is very important. These types of structures do not just block or attenuate signal, they will actually carry signal to areas you may not want it.

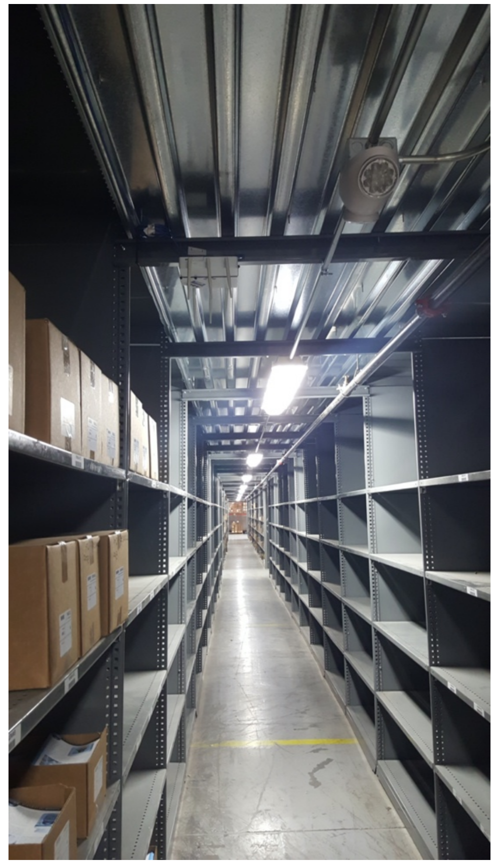

FIGURE 4

It is not uncommon to find omni-directional antennas used to provide coverage for picking modules. In some applications this type of design may provide adequate performance, but in most cases I find that this can be the source of a lot of connectivity issues in these areas. Omni-directional antennas mounted within a metal structure will create a lot of reflection and will create a high multipath environment. Most warehouse clients are 1x1 clients and do not perform well in high multipath environments. The use of directional antenna in these areas, though it is more expensive, is often a better solution. Mounting the antennas to shoot the signal down the aisle of the picking module, in a saw-tooth pattern, will help control the signal and often result in a design that maintains a better line of sight between the client and the antenna, and provides better performance.

Coverage at Multiple Heights

In most wireless network's client devices are normally only used at ground level, but in warehouses client devices are often used at many different heights, from ground level to the tops of the racks. This brings a more three-dimensional aspect into the RF design since now you must consider client elevation when designing coverage.

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For warehouses with low ceiling height this is usually not an issue, but when you are dealing with 50′ ceiling and narrow aisles, this can definitely create some challenges. Correct antenna choice and placement is critical in these cases. If you choose an antenna with too narrow of a vertical beam, and aim it too low, you may find you have great coverage on the floor, but weak signal when a user is on a lift 30′ in the air. Mount the antenna too low to the ground and you can have the same type of issue.

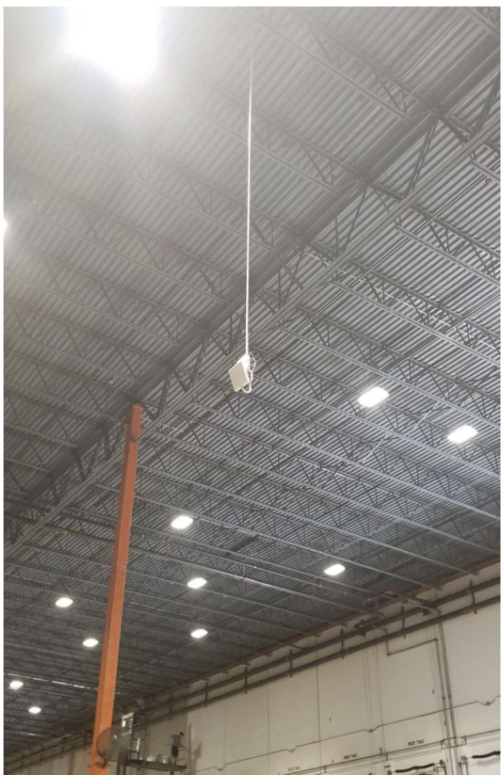

FIGURE 5

The approach I take for these situations is to use a directional antenna shooting down the aisles, focusing the signal from the antenna's main lobe at the mid-point between the floor and the highest point users will need connectivity. This will provide maximum coverage to a wider area within the aisle. When possible, I drop mount the antennas to the height needed which reduces the amount of down-tilt required, this helps focus the signal down the aisle and provides the best penetration. When drop mounting equipment you do need to be sure that it is not in an area where it could be damaged by forklifts of lift trucks.

Figure 5 shows an access point and antenna drop mounted approximately 25′ from the ceiling. Electrical conduit was used to provide a stable platform to mount the access point and antenna to and a protected path for the Ethernet cable to be run.

Inventory

When designing a wireless network, understanding the RF characteristics of the building or location you are designing for is important. Knowing what a wall or object is constructed of will help in predicting the amount of attenuation or affect it will have on the signal. In most wireless environments this is a pretty static variable. Once you determine the amount of attenuation created by a wall or object it usually doesn't change much, but with warehouses this is not the case.

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The whole purpose of a warehouse is to temporarily store inventory until it is needed. Inventory is brought in and stacked on racks, or on pallets, until it is needed to fulfill an order, which then is pulled and usually moved to another part of the warehouse for repacking and shipping. Understanding how inventory moves within a warehouse, and how much the inventory levels fluctuate will help determine the best locations for access points or antennas to minimize the impact of this change.

Changing inventory levels creates the biggest effect on the RF environment in a warehouse. As inventory level reduce, so does the amount of attenuation created by the rack in which the inventory is stored. This phenomenon can change how the signal propagates through the warehouse, the amount of isolation between access points, can affect roaming, and can also increase CCI (Co-Channel Interference). As inventory levels increase it will raise the amount of attenuation which can create holes in the RF coverage.

The type of inventory stored in the racks can also have the same type of effect on signal as inventory levels. What if a wireless design was created for an area in a warehouse where the rack stored paper products or dry goods, items that producce little attenuation. Sometime after the network is deployed the inventory in the rack is changed and now it stores liquids or dense items that produce higher attenuation levels. If the design is based on the ability for the signal to pass through the racks, then this is going to have a major impact on the signal and network performance.

Understanding the inventory in a warehouse, how the levels change, if the products change, and even how the order process moves the inventory through the warehouse, will help reveal just how dynamic the attenuation level in the environment will be. Creating a warehouse design that minimizes the amount of signal that must pass through the inventory will minimize the impact inventory has on network performance.

Climate Control

Many warehouses are not climate controlled. There are two things that immediately come to mind when I'm designing a wireless network for a site without climate control; how hot does it get? And much does the humidity change?

The temperature in a warehouse can vary as much as 20 degrees from ground level to the ceiling. If equipment is going to be ceiling mounted this difference needs to be accounted for when checking temperature operating ranges.

Humidity is often overlooked when creating a wireless design. In outdoor deployments humidity and precipitation can severely degrade performance due to the effect of absorption, reflection, and scatter. Indoor deployments are not as dramatically affected by this, but changes in humidity can still significantly change the attenuation levels of certain objects within a warehouse. Cardboard and other similar materials used to store inventory will absorb RF and attenuate the signal as it passes through them. As humidity levels in a warehouse rise, the cardboard and other materials will absorb the humidity, this in turn will increase the attenuation level of the material.

Humidity issues can be hard to troubleshoot, and even harder to prove. Customers often want a tangible root cause not something invisible that you can't change quickly to verify. And in reality, is the humidity in the warehouse truly the issue or is it the design? Based on my experience, warehouses will report more connectivity issues in the summer or high humidity months than in the winter. This to me is a big indicator that the warehouse has an RF design issue, and if this is the case, correcting the design is a lot easier than trying to control the humidity.

One way to address a humidity issue is to relocate access points or antennas so that the signal does not have to pass through the inventory or material affected by humidity, this is usually the best approach. Increasing power levels to try and fix a design issue is never a good idea. This can create a situation where the client can see the access point, but the access point cannot see the client, it will also increase the chances of CCI.

Coolers, Refrigerators and Freezers

Heat is not the only concern when it comes to temperature, extreme cold can be a big issue as well. Warehouses can have several different climate zones.

- Cooler: 46 to 59 degrees Fahrenheit.
- Refrigerator: 36 to 46 degrees Fahrenheit.
- Freezer: - 4 to 14 degrees Fahrenheit.
- Deep Freezer: -20 degrees Fahrenheit.

The normal operating range of an indoor AP is around 32 degrees Fahrenheit to about 115 degrees Fahrenheit. Access points in this range will normally work well in coolers, but are getting close to their limit in refrigerators, and are outside of their range for freezers and deep freezers. Damage to the equipment such as cracked circuit boards are a common issue seen with devices used in environments colder than that for which they are rated.

When designing for cold areas of a warehouse it is important to select equipment (access points and antennas) rated for the coldest temperature of the area in which it is to be mounted.

Another consideration is that refrigerators and freezers have thick well insulated walls which will block the signal from penetrating into, or out of the area. The inventory stored in refrigerators and freezers can also produce higher than normal levels of attenuation. The thick walls of the refrigerators and freezers can be used to the designer's advantage since this will create good RF isolation from the rest of the site, but they can also create challenges when it comes to cabling.

Mounting Restrictions

As with any wireless design, where you want to place equipment, and where you can place equipment, are often very different. There can be many reasons for mounting restrictions from aesthetics, to safety, to lack of access or cabling issues. No matter the reason, mounting restrictions can complicate the simplest of wireless designs.

The mounting restriction I come across most in warehouses is that the access point or antenna could interfere with forklift or lift truck operations, meaning that they could be hit by the lift when it's in an extended position. This is a very common issue and I have seen some very creative attempts at solving. One solution I see often is to drop mount the access point on a cable allowing it to move or swing if it is hit. Though this does help, it doesn't solve the problem. If the access point or antenna is hit by a moving lift truck there is still the possibility that even though it can swing out of the way, it can still be damaged, or its alignment changed. Another is mounting the equipment on spring mounts, which again helps but the equipment can still be damaged.

Most of the time, avoiding equipment damage due to its mounting location can be addressed during the initial design phase. Identifying how vehicle traffic moves through a warehouse, and at what height the lift trucks and forklifts can extend to, will help determine safe mounting locations for equipment. Some of the things I try to note during a design survey is areas where vehicle traffic is not allowed, or areas that vehicles are only allowed to operate with the lift fully retracted.

Mounting restrictions due to aesthetics in a warehouse are rarely an issue, but restrictions due to lack of access or issues with the ability to run cables can be a problem. In the previous section refrigerators and freezers were discussed. It is not uncommon to have coverage requirements inside these types of areas but restrictions on penetrating their refrigerator or freezer walls to run cables. This is a situation that for which there is really no good solution. Trying to cover a refrigerator or freezer from outside will produce limited performance at best. Even setting up mesh access points inside these areas to a portal AP outside has its challenges. In situations where mounting restrictions compromise the design, identifying and documenting the impact the restrictions will have on network performance, and setting expectations is the best approach.

IDF Location

The path and length of the cable runs to the access points always needs to be evaluated when considering a mounting location for equipment in any network. In a warehouse with high ceilings the location of the IDF (Intermediate Distribution Frame) is important for maintaining the shortest cable runs possible. A poorly located IDF can cause longer cable runs and sometimes the need for additional equipment or IDFs. The additional length of cable for the vertical runs to reach equipment mounted on a high ceiling, or drop mounted, needs to be accounted for.

In a small warehouse 300’x100’, about 30,000 sq ft, if the IDF is located in the front corner of the warehouse, mounted about 10’ up the wall, the additional vertical cable run to reach the ceiling could put you over the maximum distance of 328’ for an Ethernet cable to reach ceiling mounted access points in the back part of the warehouse. Take the same warehouse and mount the IDF halfway down the longest wall at the same height and now you should be within Ethernet limits for all your access points.

When possible, IDF locations should be planned out at the same time you are planning the access point locations to help optimize cabling. If you are working with an existing IDF, verifying and documenting cable lengths is an important step that should not be overlooked. I have worked warehouse issues that were due to excessive cable lengths causing the access points to brownout. The original installation was done to a single IDF to save money, but this caused some of the cable runs to be over 400’. Though this did save money on the initial installation, it cost more in the long run in trouble calls and poor performance. To correct this issue a switch was installed at the other end of the warehouse and connected back to the IDF via multimode fiber. This allowed all the access points in the back half of the warehouse to be connected via much shorter cable runs all well within Ethernet specs.

Hazardous Material

Working around hazardous materials requires special considerations depending on the category of the material.

- Class 1 – Explosive
- Class 2 – Gas
- Class 3 – Flammable Liquid
- Class 4 – Flammable Solid
- Class 5 - Oxidizing Substances, Organic Peroxides
- Class 6 – Toxic/Infectious Substances
- Class 7 – Radioactive
- Class 8 – Corrosive

- Class 9 – Miscellaneous

Each of these classes has different requirements and regulations when working and deploying equipment around them. Details on this go far beyond the scope of this paper, but just understanding that these types of materials could be present can help you generate questions in your discovery that can help identify if they are present. And if hazardous materials are identified, what type of training and safety or protective equipment will be required. For example, when working around class 1 material, special equipment or enclosures are required, not only for equipment being deployed but for test equipment used to gather data during a survey. This is to prevent any class 1 material from being exposed to any kind of ignition source. Overlooking this requirement could result in an explosion.

It is always important to ask about hazardous materials and to look for hazardous material signage during a survey. I recommend becoming familiar with NFPA (National Fire Protection Association) diamond signs and GHS (Global Harmonized System) symbols when working in warehouses and industrial spaces. The NFPA diamond signs indicate the classification of a material based on 4 categories:

- Flammability
- Reactivity
- Health
- Special

The GHS uses 9 universal symbols to depict the hazard associated with a chemical. These signs will help identify if there are hazardous materials that require extra caution, special equipment, or PPE used to work or deploy around them.

Summary

Creating a wireless design can be challenging in any environment, but due to the dynamic nature of the warehouse environment, the difficulty level increases. To create a successful warehouse wireless design, it is important to be thorough during the discovery stage and design survey, collecting and evaluating data on things like the clients, the environment, and the inventory. For large warehouses, I will often recommend deploying a small section of the design to validate before deploying the entire warehouse. Though this adds times to the deployment, it can reduce the chance of a larger scale mistake in the design.

Omni-directional antennas, in my opinion, have a limited use in warehouses. Many people will disagree with this, and there is nothing wrong with that because there is more than one way to create a wireless design. I often get asked, “What is the best directional antenna for a warehouse?” This is a very easy question to answer, the one that fits the particular application, though that is not the easy answer that everybody wants. There is no magic antenna that works

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for every warehouse or every situation. Each warehouse, and each area within a warehouse, needs to be evaluated for which antenna will work best in the design. My recommendation on using directional antennas is education. The more you know about antennas, from gain, to propagation patterns, vertical and horizontal beamwidth, front to back isolation, polarization, and even operating temperature range, the better your ability will be to choose the correct antenna for an application.

In the end it's the attention to detail in designing a wireless network where the client and network are well matched, and using the data collected to design around the dynamic variables in a warehouse, and not trying to overcome them, that will make a warehouse design successful.

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