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Identifying the best components for your wireless network

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Executive summary

This paper introduces the basic terminology used to describe wireless systems and their accessories. It also covers the basic steps for installing a typical network from designing a concept to the final system check. By following the planning and installation methods outlined in this paper, it is possible to reduce the installation time, as well as the risk of problems during installation.

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Introduction

As the demand for lower operating costs in plant facilities increases, operations personnel need to seek out and learn new ways to meet these demands.

Wireless technology has become a leading method of reducing operational expenditures. Installation costs of cabled systems as compared to wireless systems have been known to increase material and installation costs by up to 500%, or even more in hazardous areas. As a result of this, suppliers have seen a rapid increase in the market acceptance of wireless, resulting in the development of new wireless technologies and standards specifically designed to meet industry needs.

While the focus of most discussions about the usage of wireless technology is on the radio device itself, it is important to remember the installation practices and auxiliary equipment of those networks also plays a major role in the reliability of an installed network. Low quality accessories, such as antennas and coaxial cables, coupled with poor installation are some of the most common causes of failure in a wireless system.

Identifying the best components for your wireless network

Key concepts:

- Understanding key terminology and importance of wireless network components to select the fundamental parts.
- When careful and thorough in planning a network, it is possible to reduce installation time and potential installation problems.

Power measurements: Electric power is typically referred to as decibels, or dB. A dB is an abbreviation for a power ratio calculated using the below formula with both P1 and P2 being the same power unit.

$$dB = 10 \log \left(\frac{P_1}{P_2}\right)$$

In wireless communications, power is referred to as dBm. A dBm is calculated the same as a dB although P2 always equals 1 mW.

$$dBm = 10 \log \left(\frac{P}{1\ \mathrm{mW}}\right)$$

Some very common powers in wireless communications are found in the table below:

dBm Level	Power
-120 dBm	0.000000000001 mW
-110 dBm	0.00000000004 mW
-100 dBm	0.0000000001 mW
-90 dBm	0.000000001 mW
-20 dBm	0.01 mW
-10 dBm	0.1 mW
0 dBm	1 mW
10 dBm	10 mW
20 dBm	100 mW
30 dBm	1000 mW

The effect of power is doubled for every 3 dBm gain in commonly referred to power levels in the wireless industry. An increase of 6 dBm results in doubling the effective line of sight range of a wireless link.

The abbreviation dBi is used for gain of isotropic antennas. An isotropic antenna radiates equally in all directions. dBi and dBm can be added mathematically. The resultant number is in dBm.

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Link budget

A link budget of a radio path is the sum of all antenna gains, cable losses, radio transmission power, receiver sensitivity, and path loss (how much signal is lost from the transmitter to the receiver due to obstructions or free space). The remaining signal level is called the fade margin, the "cushion" between the received signal and the minimum receive threshold of the radio device. A 10-20 dB fade margin should be calculated into the link budget of the path in order to compensate for environmental changes that could attenuate the signal being transmitted. The fade margin can be increased by using higher gain antennas and lower loss coaxial cable, or increasing the transmission power when possible. **Figure 1** shows an overview of the calculations.

Antenna gain	**TX power**	**Cable loss**	**RX Thresh-old**	**Path loss**	**Fade margin**

Figure 1 **Overview on how to calculate link budget. Items shown in green are added while items shown in red are subtracted. The resultant number is the link budget. The fade margin is recommended to be an extra 20 dBm to account for unforseen interference.**

Antenna selection

The single most important item affecting radio performance is the antenna system. Without careful attention to this part of an installation, the performance of the entire system will be compromised. The antennas should be specifically designed for use at the intended frequency of operation and with matching impedance. Select an antenna with an appropriate gain for the path it will be used for.

Polarization of antennas: Polarization is a fundamental characteristic of an antenna. It is the direction in which the energy from the radio is emitted from an antenna through space. Antennas can be polarized in three different ways, vertically, horizontally, and radially. Cross polarizing antennas of a wireless system will result in only a fraction of the transmission power being accepted at the receiver. The fraction of the emitted power that is received depends on the angle between polarization of the antennas in the system. If an antenna is 90 degrees out of phase no power will be received. If an antenna is 45 or 135 degrees out of phase only half of the power will be received. This is the reason that proper installation of antennas is of such great importance.

For omni-directional antennas to be horizontally polarized, they need to be mounted perpendicular to ground level, where as, a yagi-directional antenna needs to be mounted parallel, or flat, with ground level to be horizontally polarized.

There can be a benefit derived from cross polarization. If two networks in the same operating frequency are installed in close proximity and interference is a resulting factor between them, it is possible to change the polarization of one entire network to overcome intrusive signals between the two networks.

Universal antenna characteristics

Omni-directional antennas

Omni-directional antennas are usually used if the position between the transmitter and the receiver can

ANTENNA SELECTION continued »

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change, moving applications or, for example, creating a multipoint network. Omni-directional antennas have almost uniform directional characteristics over a 360° horizontal plane (**Figure 2**).

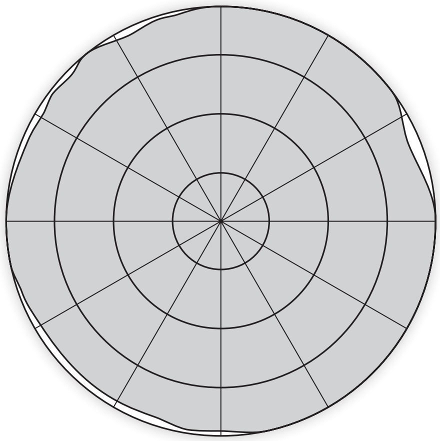

Figure 2 Omni-directional antenna radiation pattern

Omni-directional antennas are also recommended for applications with obstructed line of sight because in such cases, the signal can travel from the transmitter to the receiver via reflections.

The ideal installation location is the top of a mast or on a control cabinet, so that the antenna has the greatest possible free space in all directions. Unfortunately, it is not always possible to mount the antenna in these locations. If an omni-directional antenna is mounted on the side of a mast, specific measurements and distances must be observed.

Any conductive material that an antenna is mounted to, such as a master control cabinet, affects the directional characteristics of the antenna. Depending on the diameter and distance between the antenna and the conductive material, the antenna's area of coverage may be altered a great amount. As a result of this, wall mounting should be avoided as the wall has a great impact on the transmission properties of the antenna. If a wall mount must be used, it is important to provide at minimum 1/2 a wavelength of the respective operating frequency of distance between the wall and the antenna.

Wall-mounting antennas

Yagi-directional antennas

Yagi-directional antennas radiate power in a specific direction, allowing greater communication range and reducing the chance of interference from other users outside the pattern. **Figure 3** shows an example of a Yagi radiation pattern.

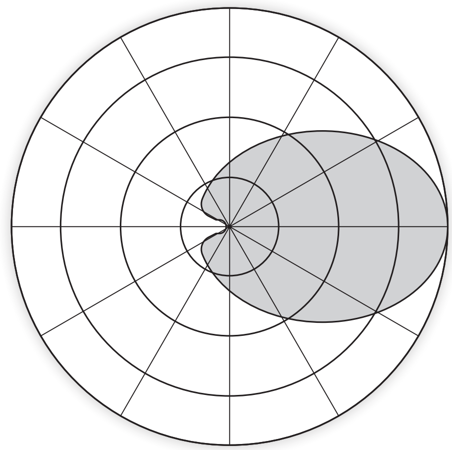

Figure 3 Yagi-directional antenna radiation pattern

As the gain of a Yagi antenna increases, the energy becomes more focused, causing the beam width to decrease, thus making proper alignment more critical. It is necessary to aim these antennas in the desired direction of communication, i.e., directed at the master station. A directional antenna is recommended at remote fixed stations when covering large distances with line of sight. The end of the antenna (farthest from support mast) should face the associated station. A master location with multiple slave radios must always have an omni-directional antenna, and the slave radios may have Yagi-directional antennas to increase distance possibilities. Final alignment of the antenna heading can be accomplished by orienting it for maximum signal strength.

With directional antennas, it is particularly important to ensure that the antenna is mounted securely. An unstable antenna may "sway" or "wobble" in strong winds, which can cause gross misalignment of antennas.

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Antenna cables

The importance of using a high-quality antenna coaxial cable is often neglected during radio installation. Using the wrong cable can cause huge reductions in efficiency or even damage the radio.

For every 3 dB of coaxial cable loss, the transmission distance is reduced by half. The choice of coaxial cable to use depends on:

- The length of cable required to span the distance between transmitter to the antenna
- The amount of signal loss that can be tolerated
- Cost considerations

For long-range transmission paths, where signal is likely to be weaker, a low-loss cable type is recommended, especially if the length of the cable must exceed 50 feet. For a short-range system, or one that requires only a short antenna coaxial cable, a less efficient cable may be acceptable, and will cost far less than large diameter cables.

The amount of loss introduced by the cable is also frequency dependent. As the radio operating frequency increases, the cable loss will also increase. Check coaxial cable datasheets carefully to determine their suitability for a specific radio frequency.

For installation purposes, the bending radius of a coaxial cable must be taken into consideration. The bending radius is the minimum radius to the inside curvature of the cable without kinking, damaging, or shortening its life span. An example of "bending radius" is shown in **Figure 4**. The bending radius of a cable is typically given on the datasheet.

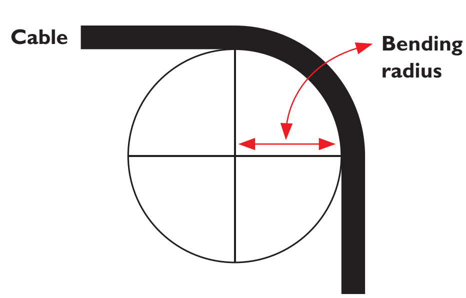

Figure 4 Example of a bending radius

Power supplies

Power supplies are often overlooked during the planning of a radio site. A radio device has some operating modes or periods that demand a high amount of power. The installed power supply must be able to provide enough current to all the connected loads, while having at least 30 percent overhead to compensate for expansion and loads that can draw variable power.

Without a sufficient power source, a radio will not operate correctly. This can result in intermittent radio links, dropped data, or resetting devices.

For high integrity sites, it is also a recommended practice to install a UPS for a backup power supply in case power fails at that site.

Proof of concept

When choosing the radio type, ensuring proof of concept is critical. Most new installations should begin with a software path loss study. The exceptions typically include distances of less than 305 m (1,000 feet), which do not require a test in 90 percent of applications, and where a simple test is done with a functional radio set to the desired wireless mode, transmit data rate and transmit power setting.

When preparing to perform a path study, first plan out where remote sites will be constructed. This can be done by traveling to each site with a handheld GPS unit, and collecting the GPS coordinates, or by using maps and other tools such as Google Earth. A path simulation uses topographic maps to plan the network virtually. It can show what obstructions may be in the way of communications, which helps to determine the ideal height of an antenna mast as well as distance between radio links. Today's advanced software makes it possible to ensure proper Fresnel zone clearance in line of sight wireless systems.

PROOF OF CONCEPT continued »

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Fresnel zone is the area around the direct line connecting the transmitting and receiving antennas. Obstacles or the terrain can disturb this zone, adversely affecting the wireless connection.

Figure 5 illustrates an ideal installation with undisturbed connection. In **Figure 6**, the terrain adversely affects the Fresnel zone. The antenna masts are set at a low level. Although there is still a line of sight, the Fresnel zone is not completely clear. This may result in a disturbed communication path.

The radius of the Fresnel zone depends on the transmission frequency and the distance between the transmitting and receiving antennas. It is generally accepted that 60 percent of the Fresnel zone should remain unobstructed to maintain a reliable path, often referred to as the 0.6 Fresnel zone. Increasing antenna heights is generally the only way to keep the 0.6 Fresnel zone clear of obstructions. The longer the distance reached by the communications, the clearer the Fresnel zone needs to be.

Although path studies provide valuable assistance in system planning, they are not perfect in their predictions. For example, it is difficult to consider the effects of man-made obstructions or foliage growth without performing an actual on-air test. Such tests can be done using temporarily installed equipment.

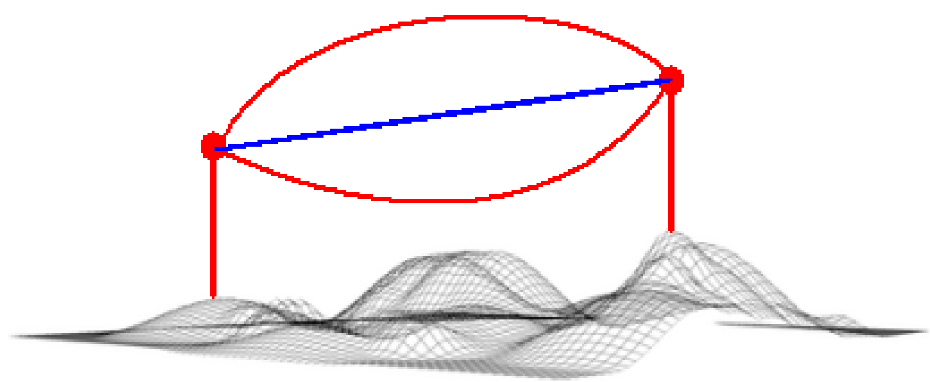

Figure 5 Clear Fresnel zone shown in red

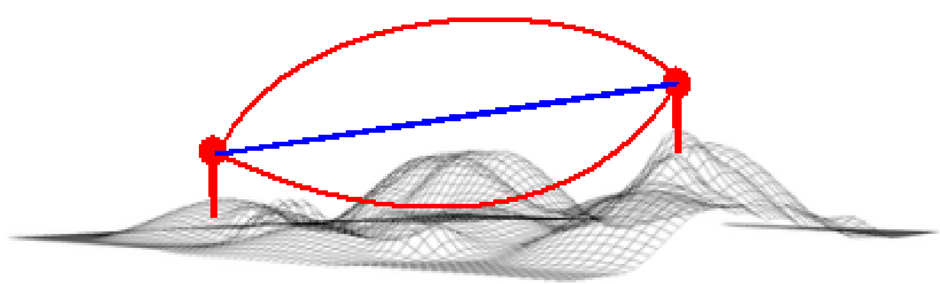

Figure 6 Interference in the Fresnel zone shown in red

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Figure 7 Typical site test setup

Field Test

A field test is recommended for applications over 1,000 feet to ensure the correct component selection.

Below are a few equipment recommendations for performing an effective field test.

- Voltmeter
- Portable antenna masts with tripods
- GPS
- Spectrum analyzer
- Watt meter
- Coaxial cable
- Antennas
- Filters
- Laptop
- Radios under test
- Power supply/battery

Watt meters and spectrum analyzers are typically expensive measurement tools; however, they can be rented at a reasonable rate for short-term use.

A spectrum analysis is an important item to consider when both planning and troubleshooting a network. A spectrum analysis measures the noise floor in the intended area of installation. This is an important item to consider because if a frequency band is prone to high interference in an area, the spectrum may want to be avoided altogether. Also, some higher quality radios have the ability to block channels in the band. So by performing a spectrum analysis prior to installation and finding any and all peaks of interference, it may be possible to block these channels directly in the radio to avoid possible problems in the network.

Every remote site needs to be tested back to the master site using varying antenna heights to find the optimal signal strength. Radio performance is directly related to how the antenna is mounted, raised and polarized.

Most omni-directional antennas are vertically polarized, so it is important to ensure that all directional Yagi antennas match the vertical polarization by having all elements perpendicular to the ground.

Using the site map and software path study created earlier as a guideline, locate each remote site to be constructed and measured under test. A good practice is to set up the master location first and work outward, from the relative closest site out to the farthest. Also, using the software study as a guideline, raise the master antenna to the height required by the farthest slave, which is typically the weakest link.

Once the master location is constructed and the radio installed, move to the first remote site to be measured. As you did at the master location, use the mast and tripod to raise the antenna to the predicted height where a 20 dB fade margin is achieved. Using a voltmeter or the radio's software measurement tool, record the received signal strength to the master and compare the reading to what was predicted in the software simulation. If a 20 dB fade margin above the receive sensitivity is not realized, raise the remote's antenna height until a 20 dB fade margin is reached. Make note of this height for final installation. Also, make sure that the antenna azimuth points directly to the master when using Yagi antennas and is polarized correctly.

Once an acceptable signal is received, it is important to verify how the RF link will transport the data that it must carry. A typical test consists of pushing data through the link that is the same or comparable to what will be used in the final installation. When this data is being pushed through, check for the packet errors that result from the wireless link.

After you have proven a reliable RF link from master to slave, carry out the same tests for all remote sites. Every site will be different in terms of antennas, cable, height and bandwidth requirements. This is why it is necessary to test both signal strength and data throughput at each site.

All remote sites must be proven reliable and effective before commissioning the system. This will prevent costly and time-consuming troubleshooting later on. Good practice in system design and installation ensures reliable sustained network performance in the future.

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Troubleshooting installed networks

Following the installation of a network, no matter the caution that was taken during planning and installation, some problems still can exist. A few early recommendations on what to look for are possible interference and the voltage standing wave ratio (VSWR). In many cases the issues may be very simple and can be fixed simply by tightening a connector. In more advanced cases, it is first recommended to perform a spectrum analysis to ensure the intended wireless data isn't being saturated by noise. Next the cabling should be tested. This is done by testing the VSWR.

VSWR

VSWR is a representation of a mis-match of impedance between the transmitter and the load impedance (antenna). To achieve maximum power, the load impedance (antenna) has to match the generator impedance (radio). In an ideal case, the VSWR would be 1:1. This is referred to as a perfect impedance match. This will allow for a maximum power transfer from the radio to the antenna. However, this ideal case is not physically possible. So the objective is to match the line to antenna impedance as close as possible to minimize power losses. Any impedance mismatch will cause a standing wave in the opposite direction of the forward power on the transmission line causing interference to the forward power and will result in a voltage maximum and minimum at ¼ wavelength increments. The greater the amplitude of these maximums and minimums, the greater the signal attenuation will be.

A watt meter can measure the forward and reflected power of a transmission line. Most watt meters measure forward power as the sum of both the forward and reflected power. This is typically done by having the tuning element pointed in the direction of the antenna. To measure reflected power, turn the element so that the element points towards the transmitter. A maximum VSWR of 1.5:1, or 5 percent return, is recommended for optimal system performance. A ratio greater than 1.5:1 indicates a problem in the cable-to-antenna terminations.

Figure 8 displays three waveforms: Incident wave, Transmitted wave, and the reflected wave. The incident wave is the waveform that was transmitted from the radio. The reflected wave is the wave that is created from any impedance in the cabling. The reflected wave is subtracted from the incident wave, and the resultant is the transmitted wave.

Most VSWR problems are due to connectors that are not fastened correctly or weather-proofed. Sealing each connector junction with weatherized vulcanizing tape

VSWR continued »

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VSWR continued »

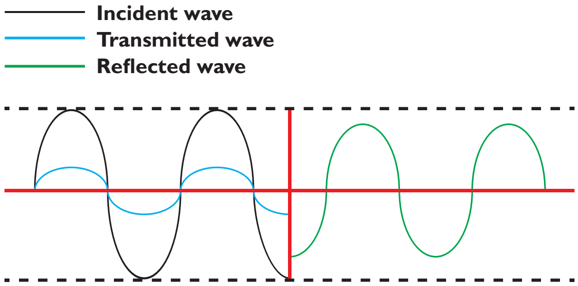

Figure 8 **Waveforms present in the coaxial cable and transmitted from the antenna displaying what happens when VSWR is present. Vertical red line represents impedance of cable or other components on the line.**

can prevent water from getting into the cable line. It will also help to keep the connectors tightly fastened.

Following installation of cables, it is highly recommended to run a VSWR check on all cables. If cables are field terminated, meaning they were built while in the field, they must be tested to ensure proper connections.

Conclusion

Most problems when troubleshooting a newly installed network result from poorly chosen or poor quality accessories. It is important to remember that quality is not an accident. From planning to installation, when the single most important goal is a high-quality network that will last longer and provide the most reliable results, choosing components is equally as important as choosing the main system.

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