UBIQUITI ACADEMY

Ubiquiti Broadband Wireless Admin

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Foreword

The *Ubiquiti Broadband Wireless Admin* (UBWA) training book is made freely available to you as a learning resource to prepare you for taking Ubiquiti certification exams. During classroom training events, students engage in real-world lab activities using the latest Ubiquiti hardware, led by a Ubiquiti-Certified Trainer proficient in the course topics to guide class discussions.

To empower our global user base, the Ubiquiti Academy provides this training book as a reference, to be used to begin and accelerate your learning - it is not a substitute for training courses led by a qualified instructor. When you're ready, sign up for an official Ubiquiti training course and gain recognition as a Ubiquiti-certified professional in your industry expertise.

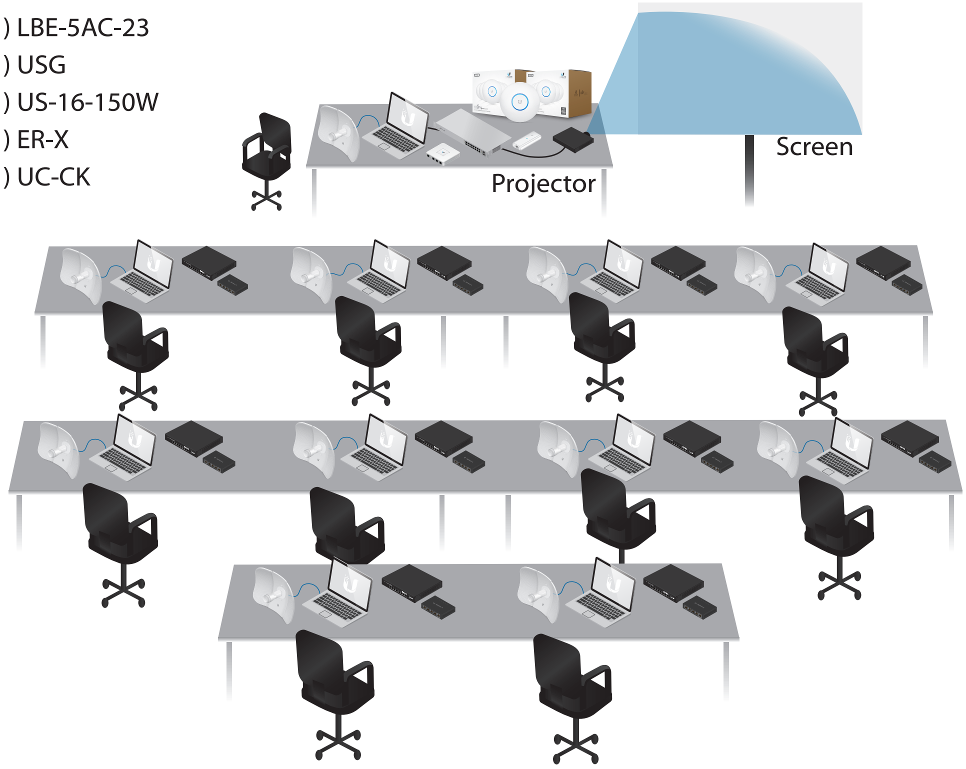
Ubiquiti acknowledges that professional success in the rapidly-evolving technological world of today requires a strong commitment to continued learning through diverse methods of study. As you read this training book, be sure to participate in our active User Community, where thousands of users come together daily to discuss best practices for configuring, deploying, and troubleshooting real-world projects designed and built on Ubiquiti's cutting-edge platforms.

Jamie Higley
Global Director of Training
Ubiquiti Networks, Inc.
March 2017

Preface

This training book is a supplementary guide to be read prior to and during the official Ubiquiti training course. Led by a Ubiquiti-Certified Trainer, Ubiquiti certification courses feature hands-on lab activities, hardware systems, and instructional slides, which together culminate into a unique learning experience.

Typical Classroom Layout



Trainer Station Hardware
(1) LBE-5AC-23
(1) USG
(1) US-16-150W
(1) ER-X
(1) UC-CK

Student Station Hardware

UBWS/UBWA	UBRSS /UBRSA	UEWA
LBE-5AC-23	ER-X ES-8-150W LBE-5AC-23	UAP-AC-LITE LBE-5AC-23

At the conclusion of the classroom event, Ubiquiti-Certified Trainers administer the online exam to students who have participated in the course and now seek training certification.

To sign up for an upcoming Ubiquiti certification course, visit www.ubnt.com/training.

I. UBWA Course Overview

Welcome to the Ubiquiti Broadband Wireless Admin course! This intermediate-level course teaches professionals in the service provider industry how to design, manage, and troubleshoot the wireless infrastructure of an ISP network, specifically using Ubiquiti equipment. The topics include:

- RF Theory & Link Planning
- Radio Operation & Modulation
- Antenna Design & Gain
- Specific Ubiquiti Features
- WISP Network Topologies

Ubiquiti Broadband Wireless Certification Track

While not a prerequisite to the UBWA course, the UBWS (Specialist) course teaches you basic, foundational wireless concepts, regardless of your technical background. It also introduces you to the vast potential of Ubiquiti's outdoor wireless products while familiarizing you with the radio web management platform, airOS. The UBWA course targets students who have some experience in wireless networking, independent of vendor. Both courses are fast-paced and feature plenty of lab activities to reinforce theory and practice technical concepts.

Lab Overview

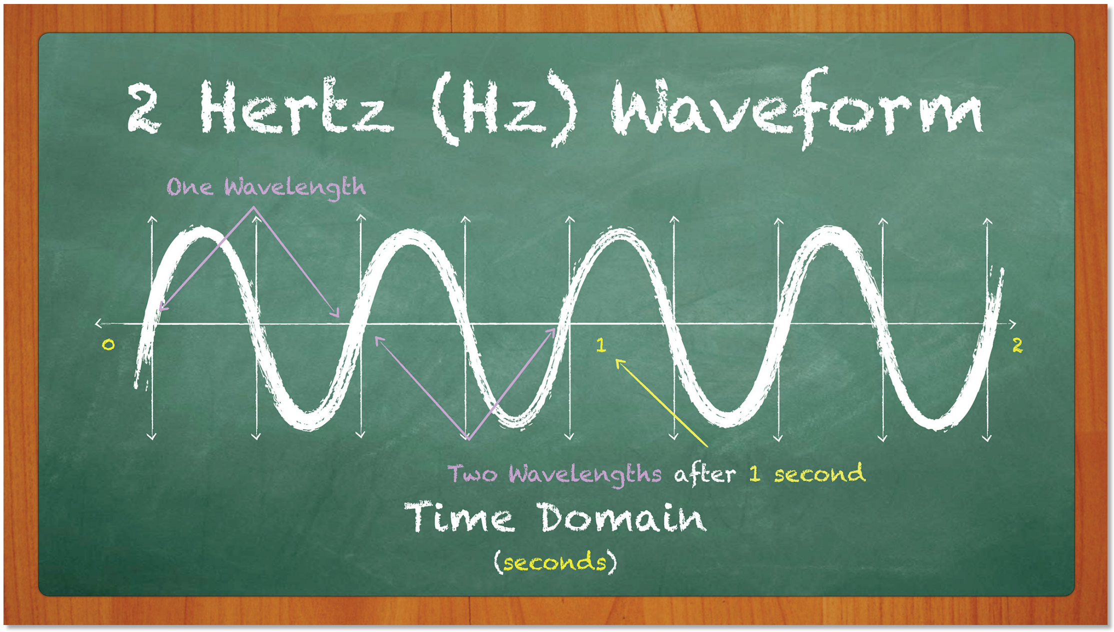
Like with the UBWS course, the UBWA lab activities are written with great detail so you can follow each step closely and understand the technical objective of the activity. Your trainer will provide you with an airMAX- ac radio/antenna (the LBE-5AC-23 is used in the course lab activities). For each lab activity, read the description at the beginning to understand the objectives. Then proceed to follow the instructions step-by-step as you configure your airMAX radio. At the conclusion of the lab activity, compare your lab topology with the topology diagram listed, then answer the questions in the review.

Your trainer will assign you a unique number (X) to differentiate your IP settings from that of others. Later, you will work in groups (Student A and B) to complete lab activities, where your unique number (Student X) is still used for reference. As an example, Student A and B work in a group and use their unique numbers (1 and 2, respectively). If the lab activity requires Student B to set an interface address to "10.1.(100+A).B", then Student B would set the interface address to "10.1.101.2", since (100+A) = (100 +1) = 101 and B = 2.

II. RF Theory

The objective of this chapter is to teach the physics of radiofrequency so you can make educated, informed decisions when planning a wireless link, regardless of distance or environment.

Wave Properties



Outdoor wireless equipment uses electromagnetic waves in order to pass data between two remote endpoints. Electromagnetic waves have two important characteristics that will be referenced throughout this course:

1. **Frequency**: The number of periodic cycles an electromagnetic wave traverses per second, measured in Hertz (Hz).
2. **Wavelength**: The length between two identical points in the same periodic cycle.

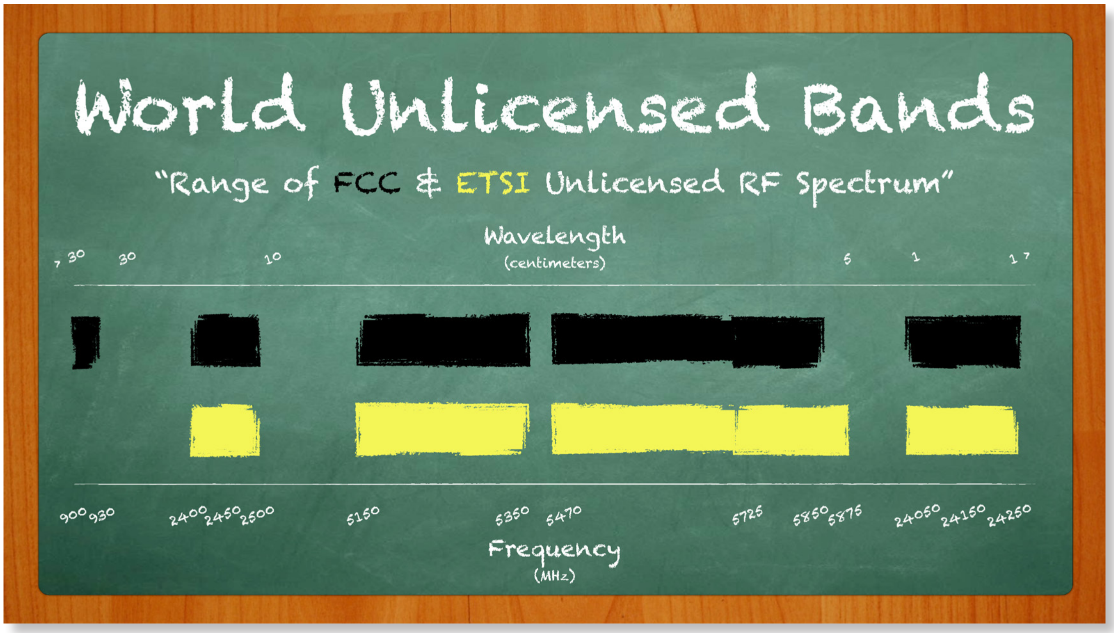
While the electromagnetic waves propagate equally well in a vacuum, diffraction and the physical properties of atmosphere cause lower frequency signals to propagate better compared to high frequency signals. Assuming all other variables remain constant (e.g., gain of the antennas, TX power), a 5 GHz signal would propagate farther than a 24 GHz signal. Likewise, a 2.4 GHz signal will propagate farther than a 5 GHz signal. In reality, other variables have an important role in the propagation of signals, and will be explored later in the chapter.

Electromagnetic Spectrum

The electromagnetic spectrum is the entire range of frequencies that encompass electromagnetic energy, such as **visible light** (what you see), **ultraviolet radiation** (from the sun rays), or **x-rays** (used in medical imaging). At the low-frequency end of this range (3-300GHz) are **microwave/radio waves**. Despite occupying a small fraction of the entire electromagnetic spectrum, Internet Service Providers (ISPs) carefully plan, then build outdoor wireless links using a combination of frequencies and channel widths to maximize speeds, minimize interference, and scale the network.

RF Spectrum

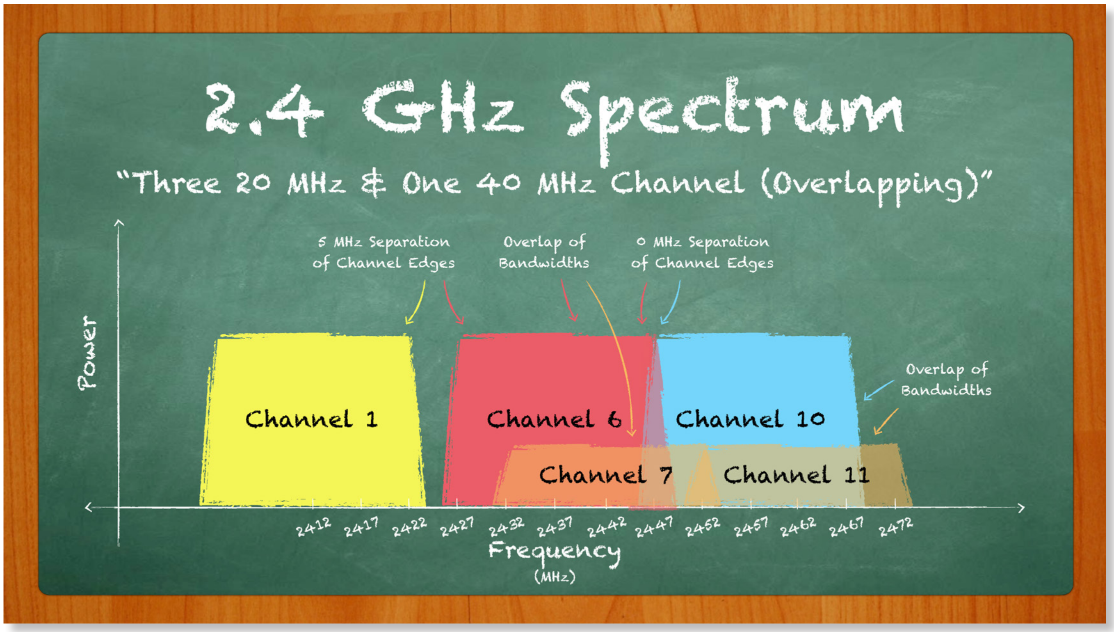
Regional government bodies exist to designate 'bands,' or ranges of frequency for given use, including telecommunications—in North America, the FCC, in Europe, the CE. These agencies allocate select bands for **unlicensed use**, meaning anyone can deploy wireless networks within the frequency range, provided their equipment complies with **regional rules** set by that agency.



2.4 GHz Spectrum

The 2.4 GHz spectrum is a **worldwide, unlicensed band**. Due to its widespread popularity across the consumer base including IP cameras, microwave ovens, and Bluetooth, wireless networks face greater interference in densely populated areas. In sparsely populated areas, the 2.4 GHz usually remains a viable option when deploying outdoor wireless links.

Although the total range of 2.4 GHz spectrum varies by region, the majority of countries designate around 83 MHz for unlicensed use. This allows for three 20 MHz wireless **channels** whose channel widths do not **overlap**: Channels 1, 6, and 11. Overlap is undesirable since it directly contributes to interference and consequently, decreased performance in wireless networks.

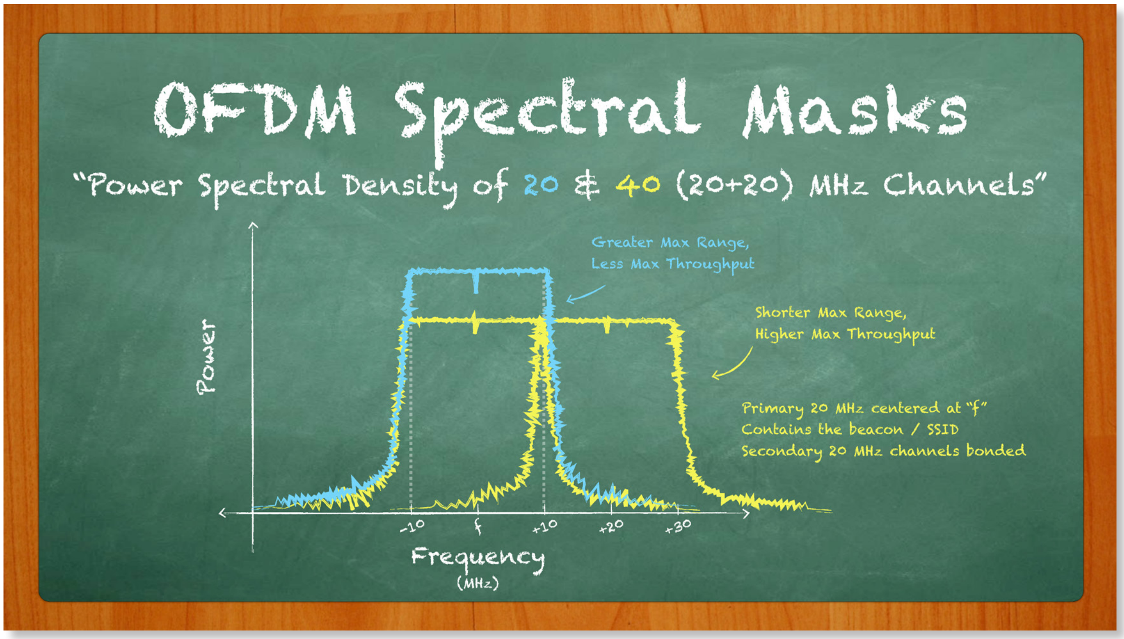


Channel width, also known as **bandwidth**, represents an entire range of frequencies used by the carrier radio to transfer data. The larger the channel width, the greater the potential for throughput. With however, a greater channel width, the power spectral density decreases, which results in lesser range. Furthermore, the more space that exists between the edges of adjacent channels, the better the wireless performance.

Outdoor wireless networks hinge on the ability to reuse channels while delivering the best possible performance. For this reason, it's always recommended to use 20 MHz or smaller channel widths in PTMP scenarios with 2.4 GHz. For larger channel widths, consider the 5 & 24 GHz worldwide unlicensed bands.

OFDM Spectral Mask

Although bandwidth represents the range of data being transmitted, it is important to understand the entire **OFDM spectral mask** as it appears to nearby radio receivers. The following figure demonstrates two transmission masks centered at frequency "f" with peak power density across the entire bandwidth. Beyond the ±10 MHz bandwidth edges of the blue transmission mask, the power level drops off along the tail ends, which can, and often do, bleed into neighbor channels.



The yellow transmission mask represents a 40 MHz channel, **bonded** by two 20 MHz channels according to the 2009-802.11n standard. The 2014-802.11ac standard identifies criteria for 80 MHz channel bonding as well. As such, larger channel widths are better-suited for the 5GHz band, where as much as 300 MHz of unlicensed spectrum is available for reuse. Despite using bonding channels like 40/80 MHz, 802.11-based APs (including airMAX ac) announce SSID on a single, **primary** 20 MHz channel. Whether a 20/40/80 MHz channel width is used is dependent on the setting at the AP and the compatibility of the Station.

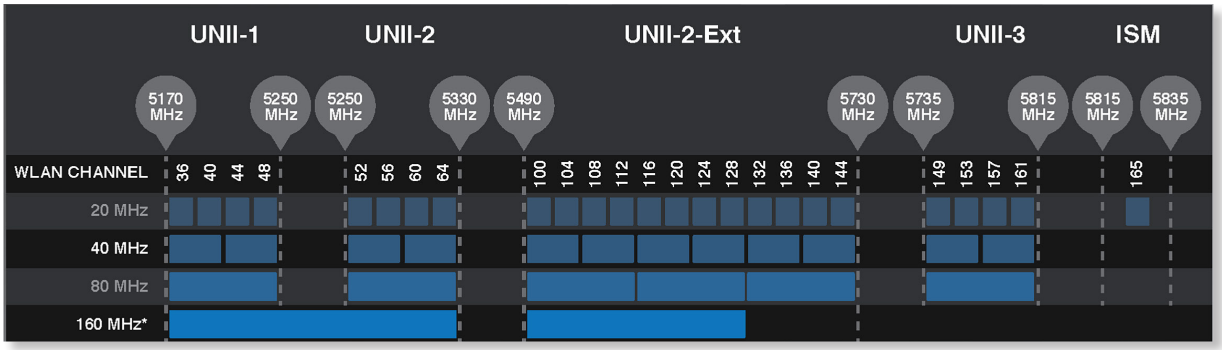
Aside from the standard 20/40/80 MHz channel widths, airMAX radios also feature custom channel widths (2/3/5/8/10/25/30/50/60 MHz) to meet the requirements for any outdoor wireless scenario. For example, in long-distance PTP applications, 5/10 MHz channel widths are desirable. It is worth noting that 30 MHz channels are not bonded but instead, are transmitted as a single transmission mask, which may be advantageous to 40 MHz bonded channels. Later in this chapter, **channel flexing**, the process by which channel width is increased/decreased to provide the best possible performance, will be explored.

Compared to airMAX, airFiber is a unique product family with advanced wireless technology. AF5 and AF24 models support **full-duplex communication** through separate TX/RX radios and antennas, allowing for the highest data rates and lowest latency possible. AF-X models are versatile products that can be paired with the best Ubiquiti antennas for high performance links across ultra long-distances. airFiber products give operators full ability to plan and deploy wireless links with high granularity (up to 1 MHz of granularity) for extremely efficient channel spacing. Additionally, airFiber supports custom channel widths at either side of the remote link, like where interference limits the available spectrum on one side, or incongruent bandwidth passes in the upstream/downstream directions.

Most importantly, airFiber's excellent spectral performance allow for side-by-side channel deployments, even in co-location scenarios. Whenever possible, choose airFiber products when deploying outdoor wireless links, to conserve spectrum, scale networks, and obtain the highest speeds possible.

5 GHz Spectrum

In most parts of the world, a clear advantage to the 5 GHz unlicensed bands is greater channel availability. The 5 GHz spectrum is divided into frequency ranges called **U-NII bands**, each with different **regulatory rules**. Depending on the selected channel, radios can operate at different **power levels**—this will be explored later in this manual.

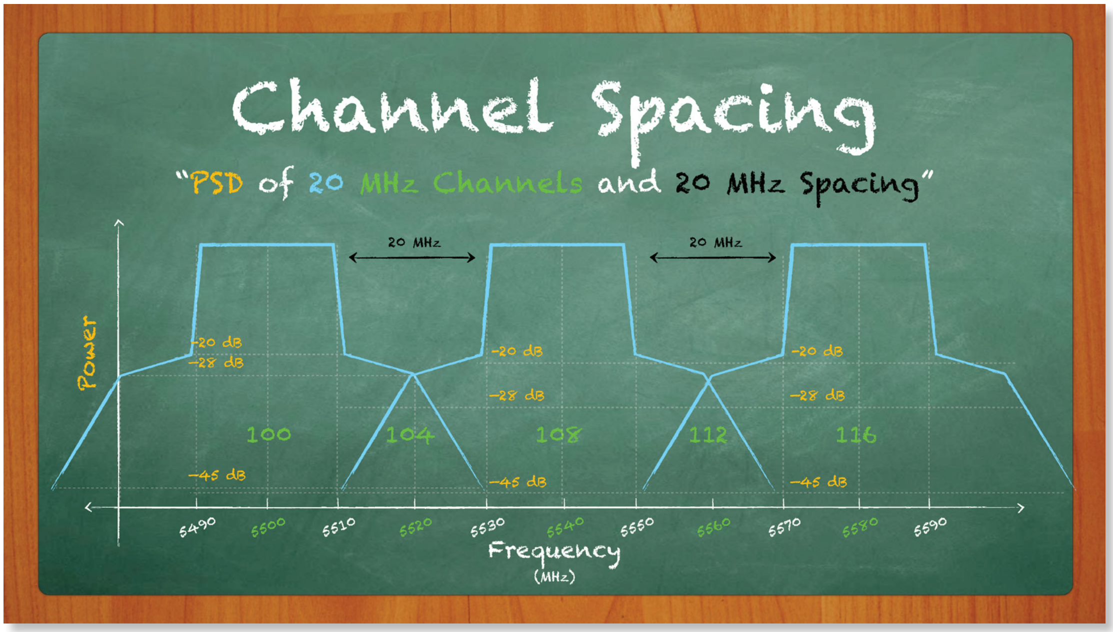


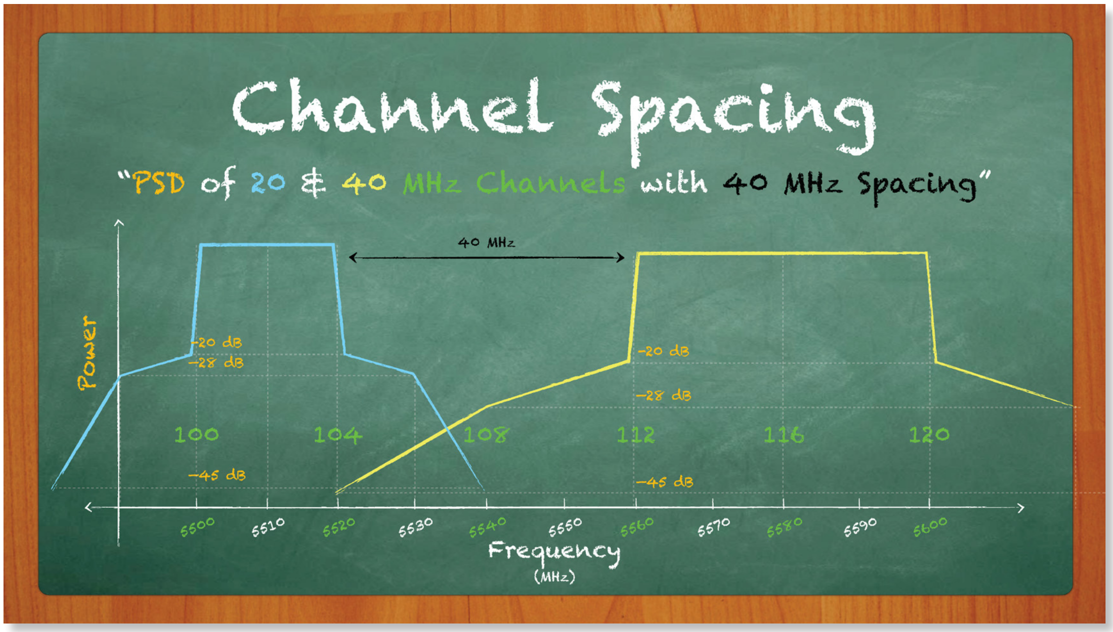
Importantly, 5 GHz radios are required to operate with **Dynamic Frequency Selection** (DFS) controls. Before using a DFS frequency, DFS-compliant radios scan certain frequencies to make sure they are unoccupied by **Terminal Doppler Weather Radar** (TDWR) and other radar systems. When operating on a DFS channel, 5 GHz airMAX radios will behave in the following manner:

- Before attempting to use a DFS channel, the radio will wait a short amount of time, listening for DFS systems. If any radar signatures are detected, the channel is blacklisted for a short period.
- When using a DFS channel, the radio listens for DFS systems in the background. If any radar signatures are detected, the radio immediately changes to an available channel based on the configured **Country Code** and **Frequency List**. The previous channel is blacklisted for a short period.

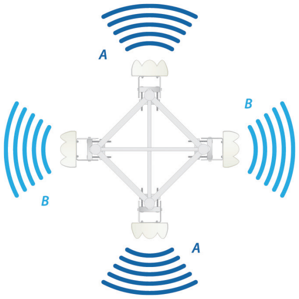
Channel Spacing & Patterns

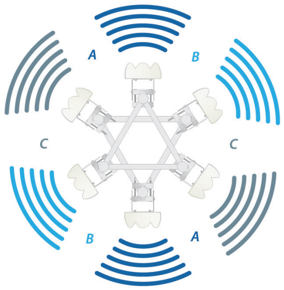
Besides knowing the available frequency ranges on which to deploy the outdoor wireless network, WISP operators must be also be conscious of **channel spacing**. Since each wireless network receives a center frequency channel, channel spacing relates the superposition of each carrier spectral mask. More channel spacing means less potential for overlap. Less overlap means less **in-band** interference, which means better wireless performance. For example, two nearby airMAX networks using 5 GHz channels 149 and 157 will interfere less than if channels 149 and 153 were used. Conversely, out-of-band signals like 2.4 and 5 GHz signals do not directly interfere with each other.





Competing, in-band networks also interfere less with each other because of **path loss**, a concept that will be explored later in this chapter. As the **physical distance** between two in-band radio networks increases, interference levels decrease. This allows channels to be reused across the geographic WISP network. For radios in close proximity, like on the same tower, high gain, directional antennas allow frequency channels to be reused in patterns. For example, if the beamwidth of the AP base station antennas are 90° or 60°, an ABAB or ABCABC **channel reuse pattern** could be used, respectively as illustrated:

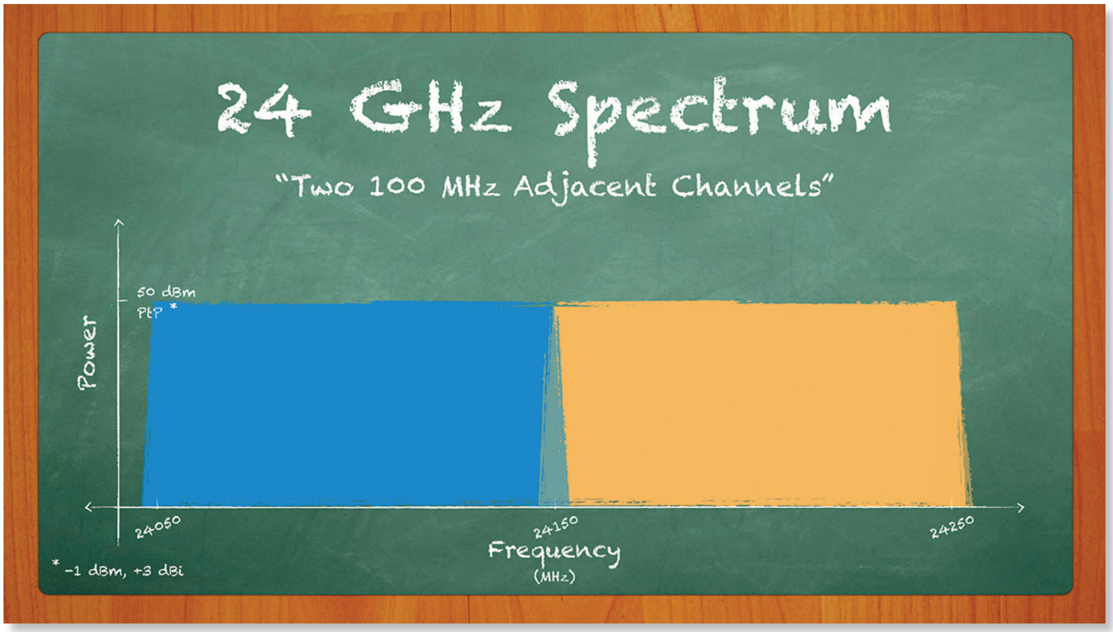




To maximize reuse efficiency, always design base station tower sites with channel patterns. To conserve spectrum, use the narrowest channel width required for the application. Co-location tips will be explained later in this manual.

24 GHz Spectrum

Beyond 2.4 and 5 GHz, the 24 GHz band is also a worldwide unlicensed band. Depending on the region, the 24 GHz band allows for as much as 200 MHz of bandwidth. Compared to lower frequencies signals, signals in the **Super High Frequency** (SHF) range like 24 GHz undergo greater attenuation. Attenuation is the rate at which a signal loses intensity, whether by **path loss** or **obstructions**. Due to their high frequency / small wavelengths, 24 GHz radio signals are particularly susceptible to atmospheric effects, including rainfall. Attenuation plays a crucial role when planning a wireless link and will be explored later in this manual.



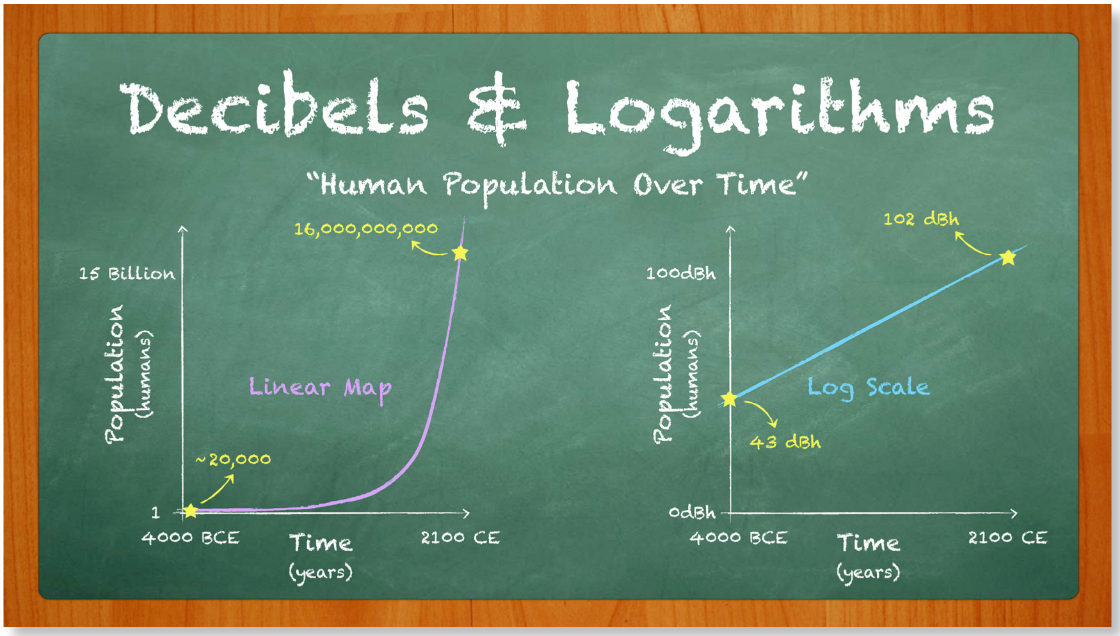
Licensed Frequencies & Compliance

In areas where the unlicensed bands are **saturated**, in-band interference levels may prove too high for WISPs wanting to scale networks to larger sizes using common frequencies. In this way, the **licensed radio spectrum** is a useful, albeit expensive, alternative for backhaul or even PTMP. Compared to 2.4 or 5 GHz, licensed bands are regulated, meaning operators provide specific information to governing bodies and pay annually for use. Licensed frequencies are especially popular in backhaul links due to the low noise levels.

In order to provide the software and documentation that reflect new regional rules, Ubiquiti's teams regularly post new firmware updates under the Downloads section, or compliance documentation under the Compliance section:
https://www.ubnt.com/compliance/.

Decibels in RF Systems

Despite their simplicity, the Ubiquiti radios and antennas deployed in outdoor wireless networks are very powerful equipment. They are also extremely sensitive devices that can work with extremely low power levels. To express these very large or small numbers, **decibels** are used. Really, a decibel (dB) is just a ratio—by itself it means nothing. But when applied to some real-world value like humans (dBh), you can map the linear function to a logarithmic scale.



In the RF world, **milliwatts** (mW) are the real-world value. The signal of a radio transmitter operating at 100mW **output power** could undergo enough loss to reach the receiver at an average power level of .0000001mW. When expressing these values, use a power ratio: **dBm**, or **decibels over milliwatt**. 0 dBm (a logarithmic ratio) is equal to 1 mW (a real-world value).

With 0 dBm as a reference point, you can begin to estimate and calculate power levels based on the **Rule of 3's and 10's**. The Rule of 3's and 10's maps the logarithmic scale to the linear, real-world values. Each time you **add 3 dB**, you must multiply the linear value **by a factor of 2**. And each time you **add 10 dB**, you must multiply the linear value by a **factor of 10**.

For example, what is the milliwatt value of 13 dBm? Because 0 dBm is equal to 1 mW, you can add 3 dBm and 10 dBm to arrive at 13 dBm.

0 dBm = 1 mW

+3 dBm = x 2

3 dBm = 2 mW

+10 dBm = x 10

13 dBm = 20 mW

Therefore, 13 dBm is equal to 20 mW.

The Rule of 3's and 10's also states that each time you **subtract 3 dB**, you must divide the linear value by a **factor of 2**. And each time you **subtract 10 dB**, you must divide the linear value by a **factor of 10**.

For example, what is the milliwatt value of -9 dBm? Because 0 dBm is equal to 1 mW, you can subtract 3 dBm three times to arrive at -9 dBm.

0 dBm = 1 mW

-3 dBm = ÷ 2

-3 dBm = 0.5 mW

-3 dBm = ÷ 2

-6 dBm = 0.25 mW

-3 dBm = ÷ 2

-9 dBm = 0.125 mW

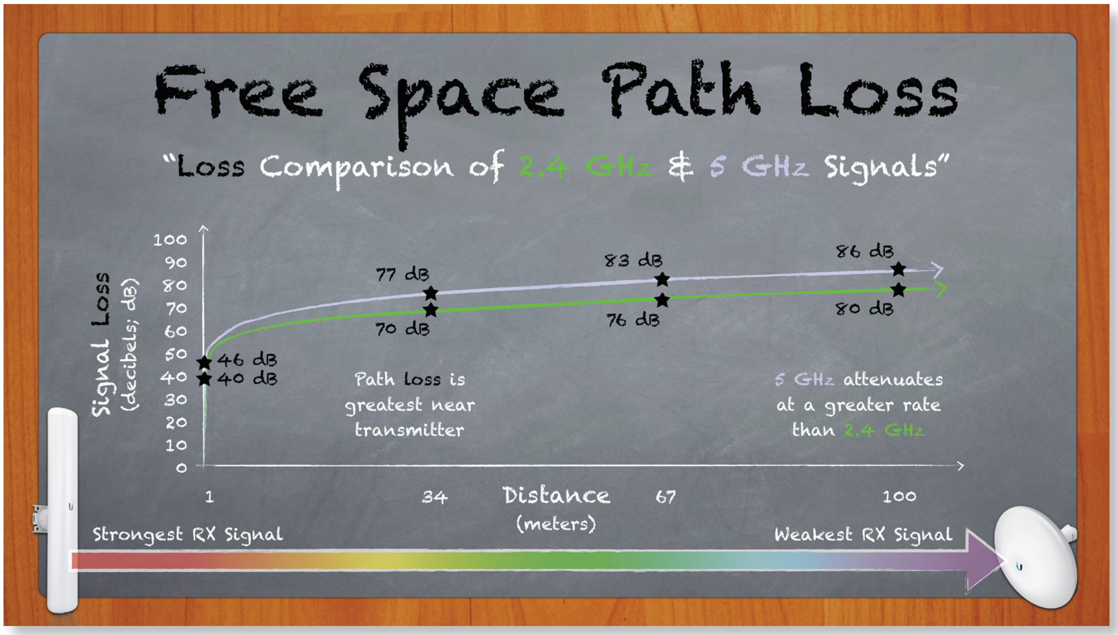
Therefore, -9 dBm is equal to 0.125 mW.

Each time you add or subtract decibels (the log scale), you must apply the appropriate function (multiply or divide) by the appropriate factor (2 or 10) to the linear side.

Decibels & Free Space Path Loss

As a radio signal leaves the transmitter antenna, it undergoes a phenomenon known as **Free Space Path Loss** (FSPL) or **Path Loss**. Path loss explains that as a signal propagates through space, it expands outward, resulting in a reduction in power levels. While true of all radio signals, higher frequency signals (e.g., 5 GHz) undergo greater path loss compared to lower frequency signals (e.g., 2.4 GHz).

The following figure relates the FSPL of a 2.4 GHz radio signal. Loss (measured in dB) is greatest within the first 100 meters of the signal leaving the transmitter antenna. Keep in mind that the figure shows a logarithmic scale. The rate at which a signal's power drops over a given distance is very rapid. "Clean" output power from an efficient transmitter and high gain antennas helps compensate for the dramatic effects of path loss.



Decibels & Antennas

Decibels are also used to express **antenna gain**. **Decibels over isotropic** radiator (dBi) measures the ability of a radiator to radiate in a particular direction relative to an **isotropic radiator**. An isotropic radiator is a **theoretical antenna** that radiates in all directions equally, similar to a light bulb. Since no antenna system is perfectly efficient (meaning loss in energy), gain is introduced to produce radiation patterns in a given direction. Antenna gain will be explored later in this manual.

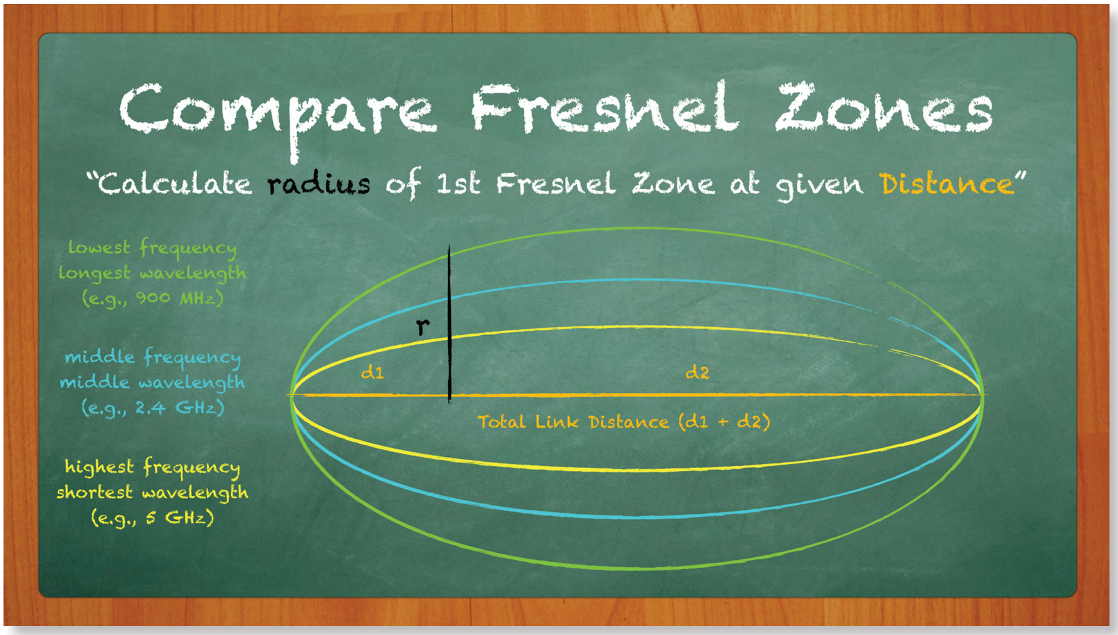
Decibels & EIRP

Regulatory bodies place limits on how much power can exit an RF system (radio and antenna). The total amount of power leaving the RF system is called the **Effective Isotropic Radiated Power** (EIRP), which considers transmit power, antenna gain, and any loss (e.g., RF cables, connectors).

To calculate the total EIRP of a radio system, sum the Transmit Power and Antenna Gain, while subtracting any loss (Ubiquiti radios typically incur under 1 dB of loss). In order to comply with regulatory standards, Ubiquiti radios will automatically adjust Transmit Power based on the selected Country Code, Frequency, and Antenna Gain.

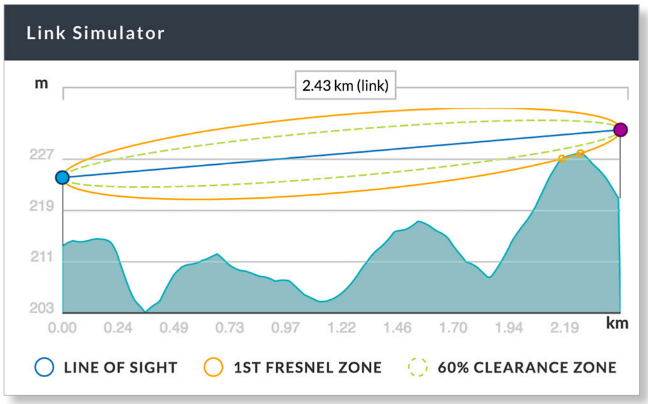
Line-of-Sight & Fresnel Zones

An important requirement for achieving the highest possible performance in any outdoor wireless link is keeping a clear line-of-sight. Line-of-sight refers to an elliptically-shaped area between both ends of the radio link. This area divides into progressively larger zones, called Fresnel zones. Within these zones, common obstructions like foliage, metal surfaces, and even rainfall can result in scattered or reflected signals. With outdoor wireless, such signals can cause multipath, which can negatively impact the receive signal.

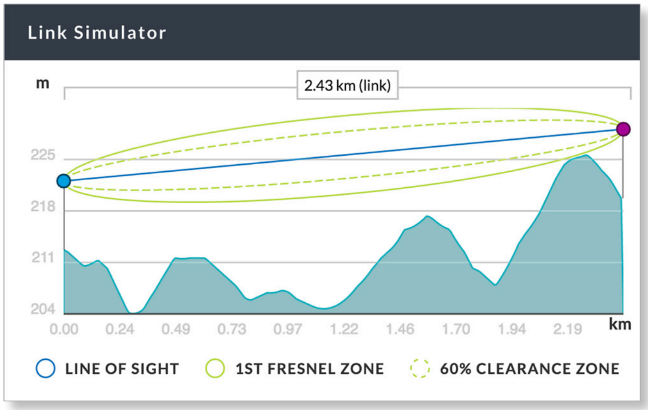


Fresnel zones are measured according to the radius at a given distance. As illustrated, Fresnel zones have a shape similar to an ellipsoid, where the radius is largest at the center of the ellipsoid—exactly half the total link distance. Consider the following rules concerning Fresnel zones:

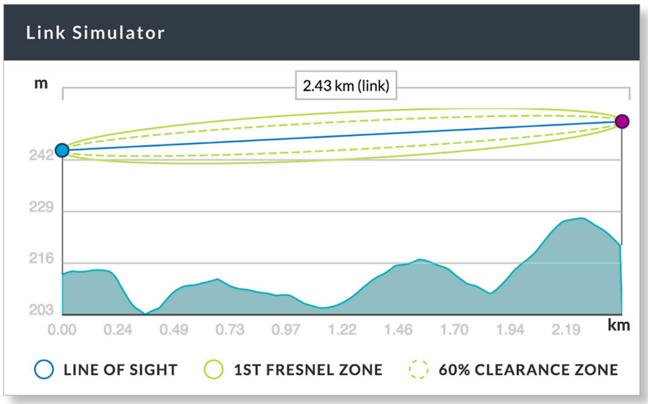
- As link distance increases, the radius also increases.
- As the frequency of the radio link decreases, the radius also increases.
- The less obstructions to the link, the better the performance.
- 60% of the first Fresnel zone must remain free to achieve a successful link.
- Mount the antenna at a greater height to clear Fresnel zones
- Keep in mind that Ubiquiti airLink software only considers terrain elevation (per Google Earth) and not physical objects (ex. trees, buildings) that could obstruct the Fresnel zones.



PtP Link with 1st Fresnel zone obstructed.



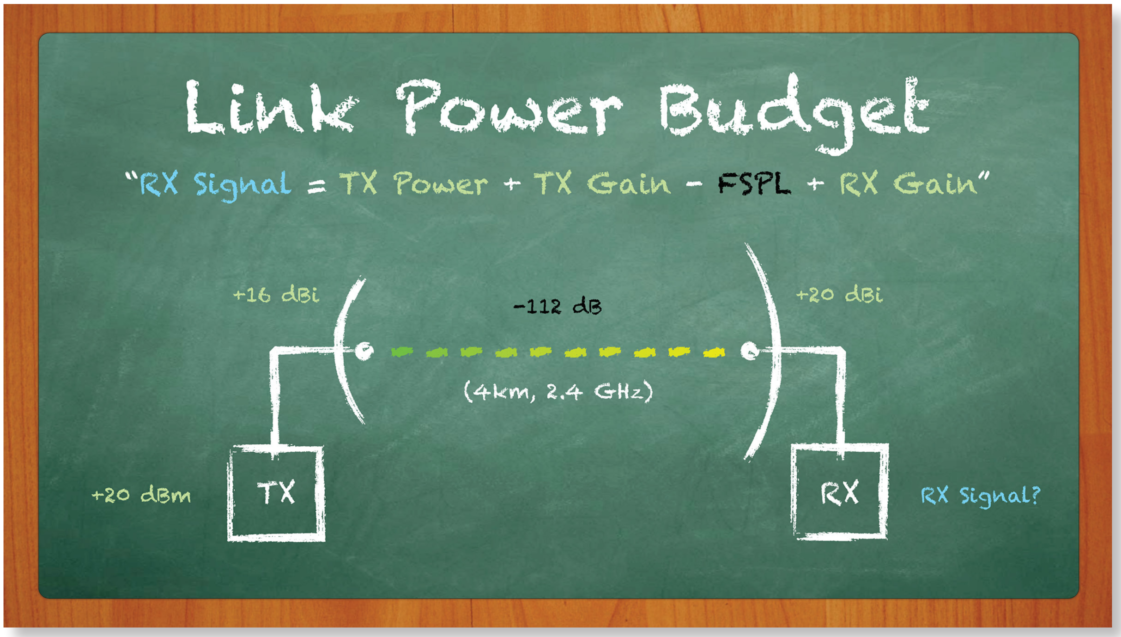
PtP Link with 1st Fresnel zone unobstructed, but likely obstructed by ground objects due to low mount height.



PtP Link with 1st Fresnel zone unobstructed, and mounted sufficiently high to avoid obstruction by objects.

Link Power Budgets

Now that you have explored the fundamentals of radiofrequency, you can begin to make accurate estimates about the **receive signal** relative to **distance**, **transmit power**, **antenna gain** and other wireless link parameters. These estimates are also called **link power budgets**. Although Ubiquiti makes free link simulation software that presents results in an intuitive, graphical manner, the following figure demonstrates how to calculate a link power budget.



Fade Margin

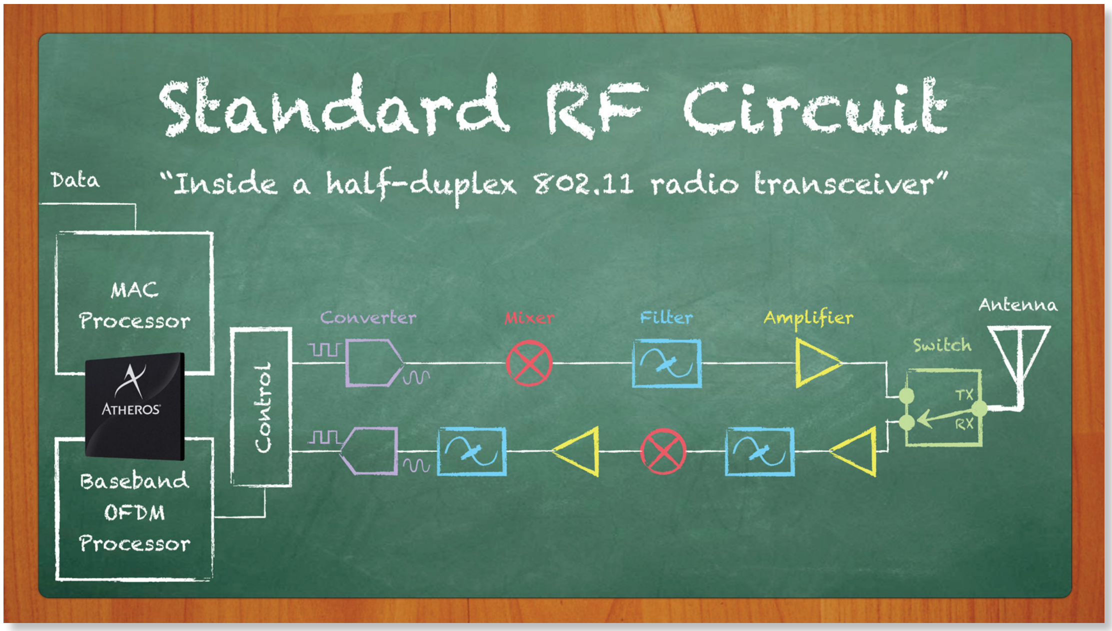
Over time, a dynamic environment can influence the performance of a wireless link. To account for changes in precipitation, foliage, and even atmospheric pressure, wireless operators typically introduce **fade margin** or a signal buffer planning a link power budgets. The greater the fade margin, the more resistant your wireless link will be to possible change. Higher fade margin can also help maintain good performance in RF environments where competing, in-band interference threaten the SNR.

Greater fade margin also equates to higher reliability (e.g., 99.999% uptime). Ubiquiti recommends a fade margin of at least 15 dB for CPE installs in PTMP networks. This means if you target a receive signal strength of -65 dBm, you should plan to use equipment capable of achieving a signal of -50 dBm. Backhaul PTP links will benefit from even greater fade margin (e.g., 21+ dB) for even higher reliability and more robust SNR.

III. Radio Operation

RF systems are composed of two main components: Radios and Antennas (to be explored in the next chapter of this manual). With focus on the principal characteristics that define radio operation, specifically Ubiquiti radios, this chapter will also provide insight for how to achieve the best possible performance for your PTP and PTMP wireless networks.

Carrier Radio Diagram



In order to send data across a wireless link, a transmit radio generates a **carrier signal**. Through a process known as **modulation,** the **frequency**, **amplitude** or **phase** of this carrier signal are modified to represent different **symbol sets** (groups of data bits). At the remote side of the wireless link, a receive radio **demodulates** the carrier signal to retrieve the data. A typical radio has a number of components that are responsible for different layer functions to prepare the carrier signal:

Digital Encoding Components

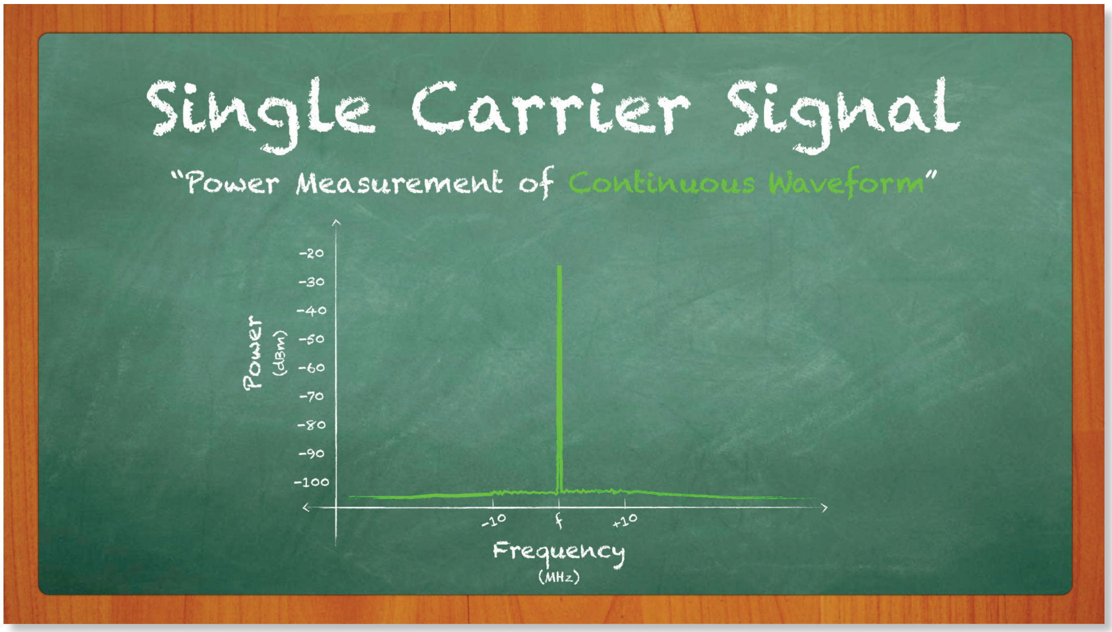
- **MAC Processor**: Beyond passing the data stream from the network layer to the baseband processor, it also handles 802.11e/i (QoS/Security) processes.
- **Baseband Processor**: Places line-coded, independent data sets onto physical OFDM sub-channels.
- **Data/Control Interface**: References time for data passing between the Baseband Processor and Front-End RF Devices (e.g., Amplifiers, Filters).

Front-End RF Components

- **D/A & A/D**: Converts signals from Digital-to-Analog and Analog-to-Digital, respectively.
- **Filters**: Designed to allow signals belonging to a particular band/frequency pass through, rejecting signals outside this range.
- **Mixer**: Generates a higher/lower frequency signal based on an input signal and a local oscillator to improve selectivity/filtering.
- **Amplifier**: Increases the power of the signal.
- **Chain**: Another name for a transceiver (a radio transmitter/receiver).

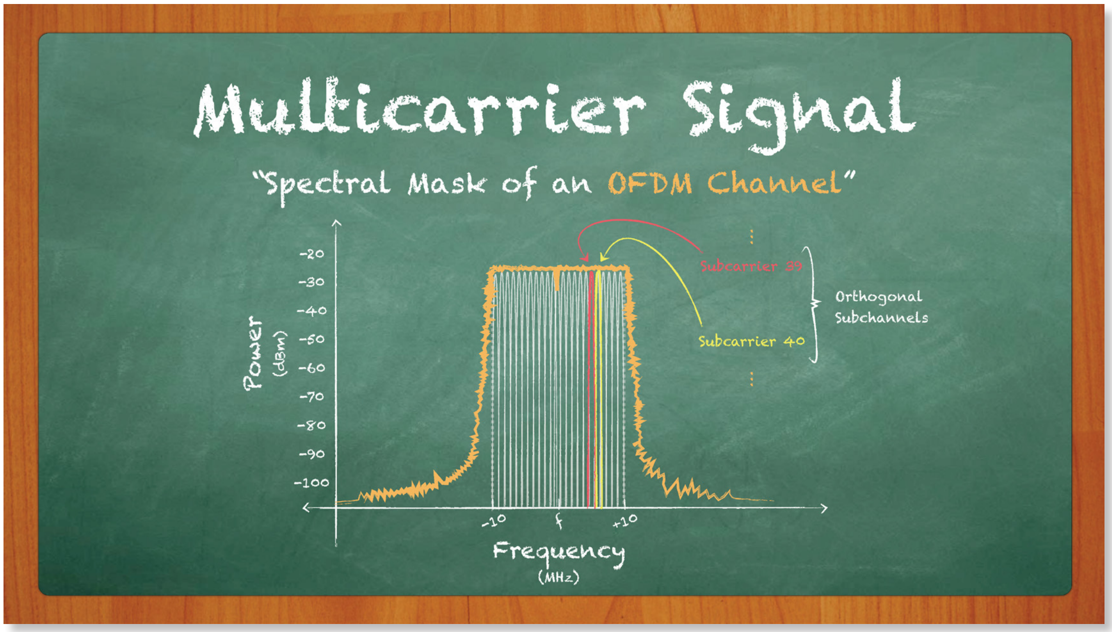
Single Carrier Signal

A **continuous waveform** (CW) is an example of a single, constant carrier signal. None of its wave properties—frequency, phase, and amplitude—are modified. In early radio networks, the CW signal was switched on/off to communicate like with Morse code to represent different data.



Multicarrier Signal (OFDM)

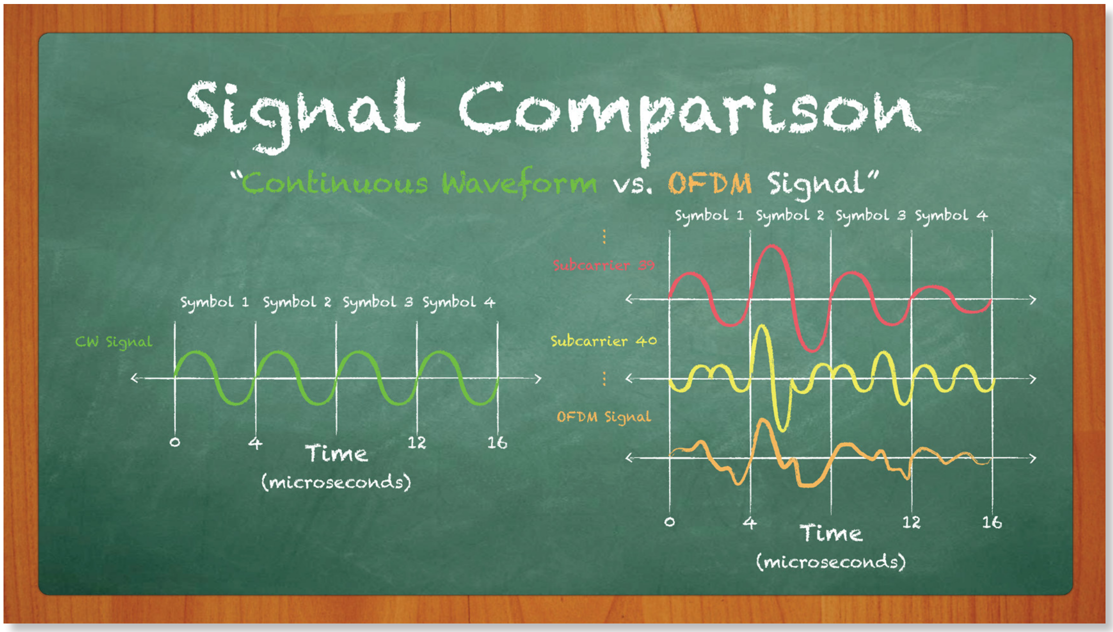
Using advanced methods like OFDM, modern radios divide the channel width into multiple, smaller **subchannels**, or **subcarriers,** for increased throughput. The use of subcarriers makes OFDM robust against multipath effects, a phenomenon that leads to decreased signal strength in outdoor wireless. Due to their orthogonal (equally spaced) nature, the individual subchannels do not interfere with each other.



Multicarrier Signal

"Spectral Mask of an OFDM Channel"

The superposition of the subcarrier signals produces a very complex waveform, different from each of the individual waveforms. This is because each individual subcarrier is independently modulated.



Signal Comparison

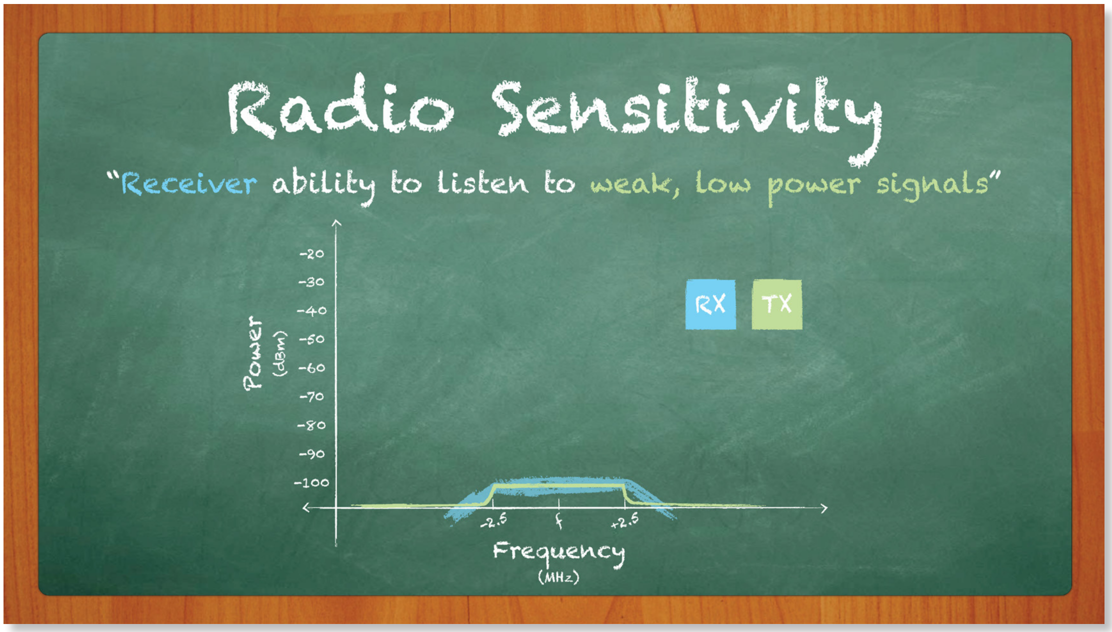
"Continuous Waveform vs. OFDM Signal"

RF Front-End Characteristics

The **RF Front-End** describes the radio circuitry responsible for processing the carrier signal. To overcome challenges posed by noise and interference sources, both transmitter and receiver must be equipped with both high quality components and the latest hardware technology, like airPrism and airMAX ac. Radio operators who invest in and properly deploy Ubiquiti outdoor wireless equipment ensure that their networks function stably and scale well. This in large part due to the exceptional sensitivity and selectivity performance of their radio receivers.

Radio Sensitivity

The primary job of the receiver radio is to 'hear' signals from a desired transmitter. As explained in the previous chapter, free space path loss causes a signal to rapidly drop in intensity as it propagates through space. The result is often a very, very weak signal arriving at the receiver, which makes **sensitivity** one of the most important characteristics of the radio. Sensitivity defines the radio's ability to 'listen' to weakened signals. The greater the sensitivity of the radio, the weaker the signals it can receive.

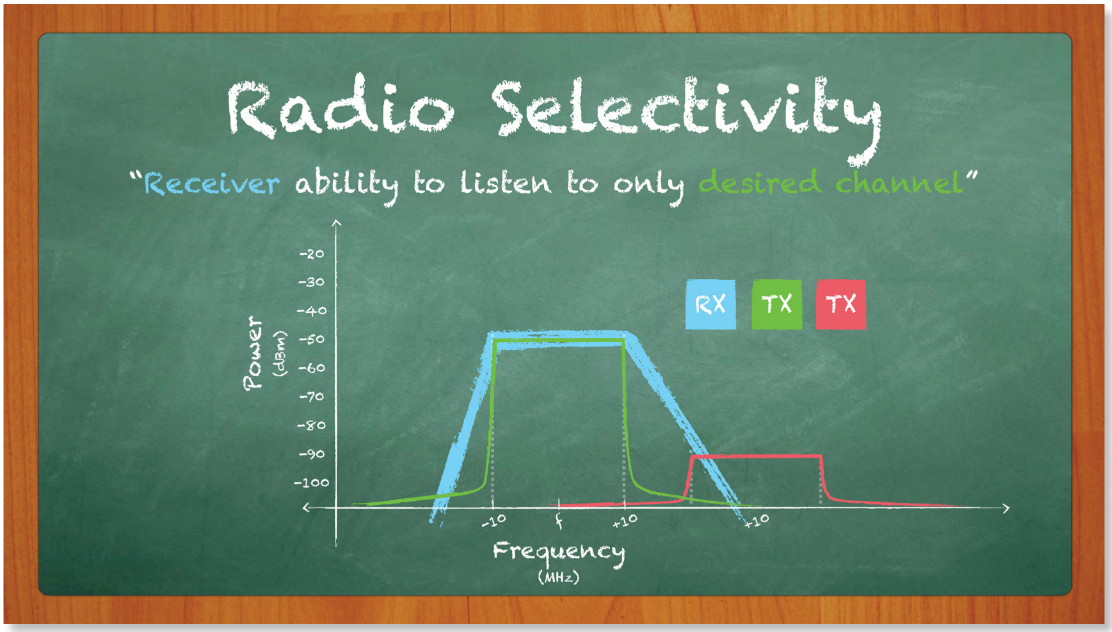


Amid a 'clean' RF environment, the finely-tuned receiver components of Ubiquiti radios can 'hear' ultra-low signals—in some cases, as low as -103 dBm (0.000000001mW)! Regardless of whether the receive signal is weak or strong, radio communication demands this signal be stronger than the total combined noise and interference levels.

Radio Selectivity

In order to minimize the effect of interference from neighboring channels, the receiver radio needs adequate filtering. The ability of the receiver to 'listen' to the desired signal while blocking out other **in-band** channel sources is known as radio **selectivity**. As an example, in-band interference for 2.4 GHz spectrum refers to undesired signals across channels 1-11 (1-13 where available).

The following figure shows a receiver radio (blue) with tight filtering -10 MHz below the center f of the transmit channel (green). However, +10 MHz above the center f of the transmit channel, poor filtering/selectivity increases the amount of in-band interference 'heard' by the receiver.



Interference, combined with noise sources local to the receiver, contribute to the overall **signal-to-noise ratio** (SNR). Poor SNR decreases the maximum possible data rate while increasing latency.

Wireless Measurements

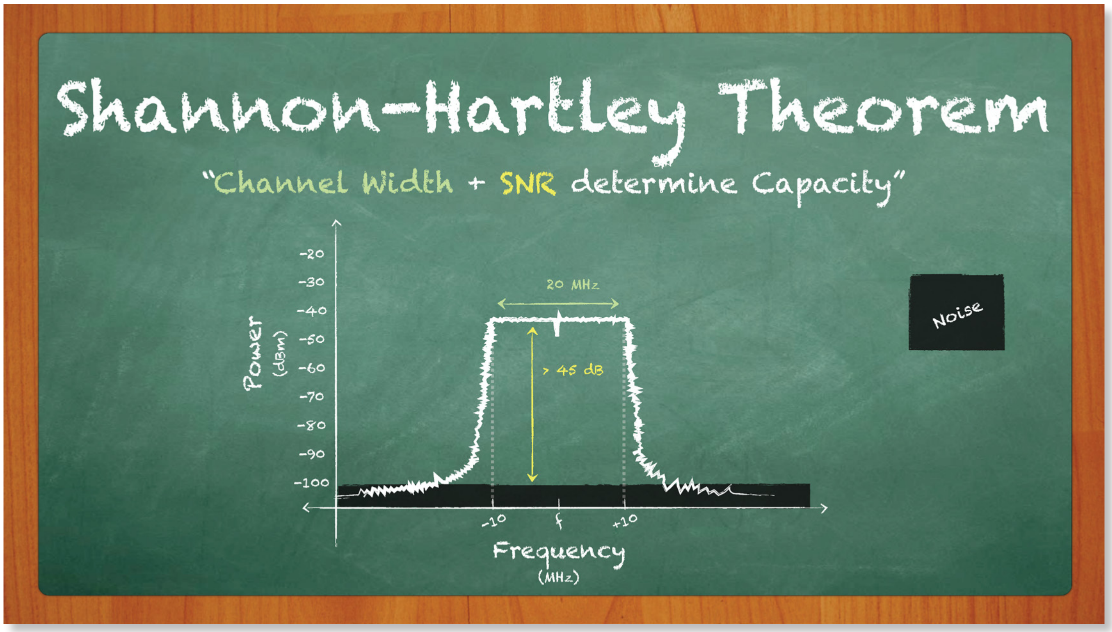
airOS reports and tracks the most important statistics for managing outdoor wireless networks, including:

- **RX Signal**: also known as **Signal Strength** or **Receive Signal**, represents the average energy level arriving at the receiver summed across both radio chains.
- **RX Chain 0 / 1**: represents the average energy level arriving at each receiver chain.
- **Interference**: represents the average energy level derived from sources of EMI sources, principally competing radio networks. The more channel overlap exists between the receiver and nearby networks, the higher the interference levels.
- **Noise Floor**: represents the average energy level derived from local noise sources, including receiver radio operation and **thermal noise**.

Thermal noise inherently impedes the sensitivity of radio receivers, due mainly to competing power from randomly moving electrons in the receiver circuitry. A narrower channel means less of that undesired power factors into the received signal. For this reason, smaller channels like 5 and 10 MHz are ideally-suited for long-range, PTP links where a low receive signal necessitates the lowest possible thermal noise level to keep Signal-to-Noise Ratio (SNR) sufficiently high for the radio link.

Signal-to-Noise Ratio & Channel Flexing

It is generally understood that a strong receive signal is necessary to obtain a robust, high-throughput radio link. But a strong receive signal does little good if the overall noise levels are equally as strong. In this way, SNR directly relates to data rates. Calculate SNR (in dB) by finding the difference in the RX Signal and combined overall level of Interference/Noise.



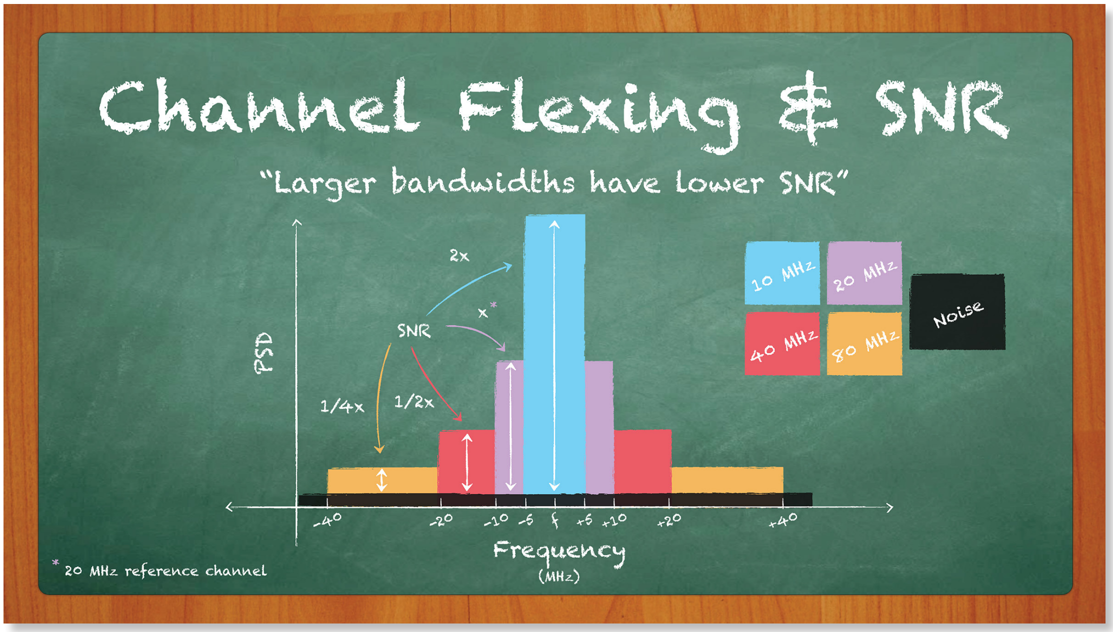
The **Shannon-Hartley's Theorem** states that the maximum data capacity of an information channel is dependent on two properties: **SNR** and **channel width**. Both properties are positively correlated with data capacity. In theory, as SNR or channel width increases, data capacity also increases.

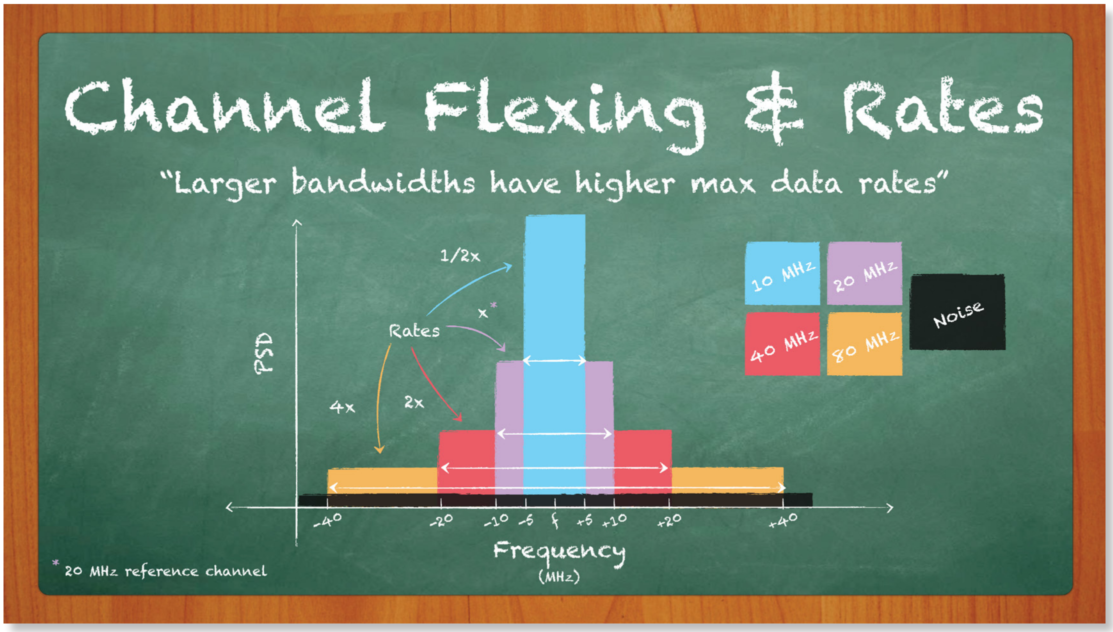
In practice however, using a larger channel width has a few implications, namely:

- Increased noise floor due to thermal noise,
- Potential to encounter more interference across the channel, and,
- Lower **Power Spectral Density** (PSD).

PSD represents the amount of energy relative to the transmitted signal across the entire channel bandwidth. Whether using a large or small channel width, the transmitter will still operate at a given TX power level, meaning smaller channel widths will have a higher peak PSD. This makes smaller channel widths appropriate for long-distance PTP links, since the signal will propagate farther before path loss causes the signal to weaken to levels comparable to the noise floor.

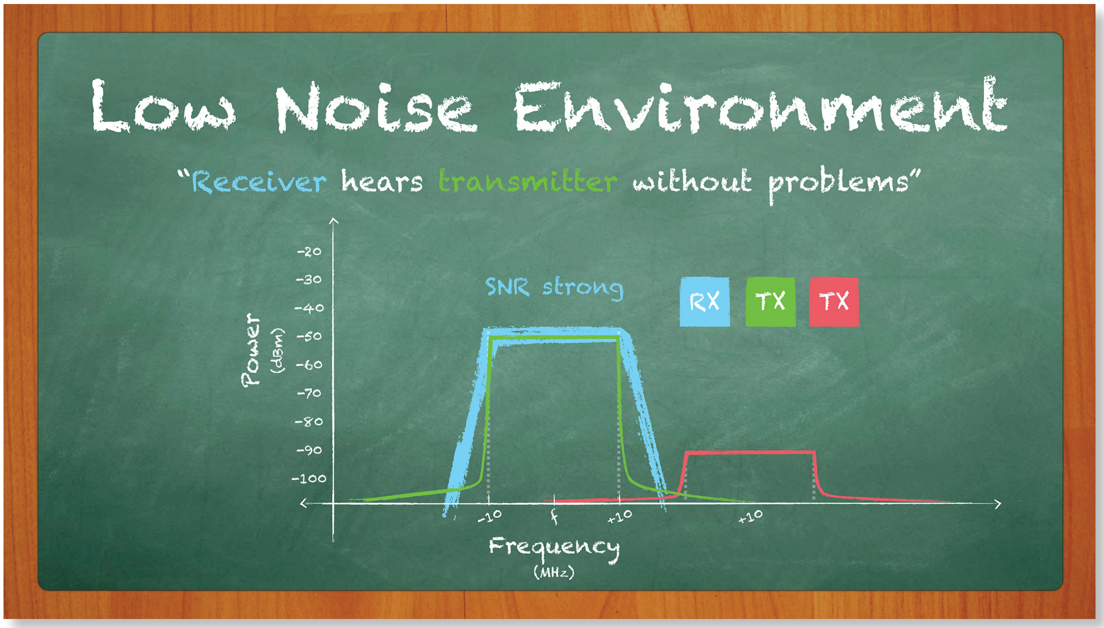
In outdoor wireless networks, channel flexing is the process by which the channel width is adjusted to meet the needs of the wireless link. Increased channel width means increased throughput potential, while decreased channel width means increased power density (greater signal strength). Whatever the requirement for your wireless network, you should understand how channel flexing relates to available channel space, data capacity, as well as SNR.





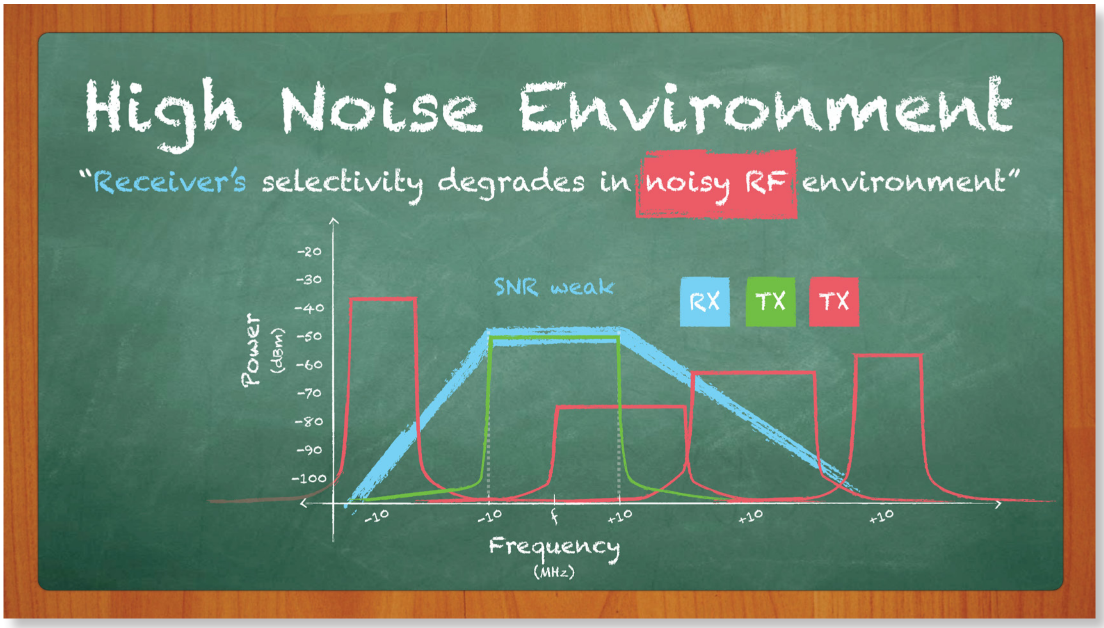
Ubiquiti airPrism

Crowded, noisy RF environments are a growing problem for WISPs. Despite a simple, low-cost, low-power consumption design, the standard 802.11 receivers prevalent in today's outdoor wireless market face major selectivity problems when operating in high-noise environments. Even if interfering signals exist on '**non-overlapping**' channels, when strong enough, such interference can degrade the receiver's filter and selectivity functions. Essentially the receiver is no longer able to clearly distinguish the desired signal from noise on other in-band channels.



Low Noise Environment

"Receiver hears transmitter without problems"



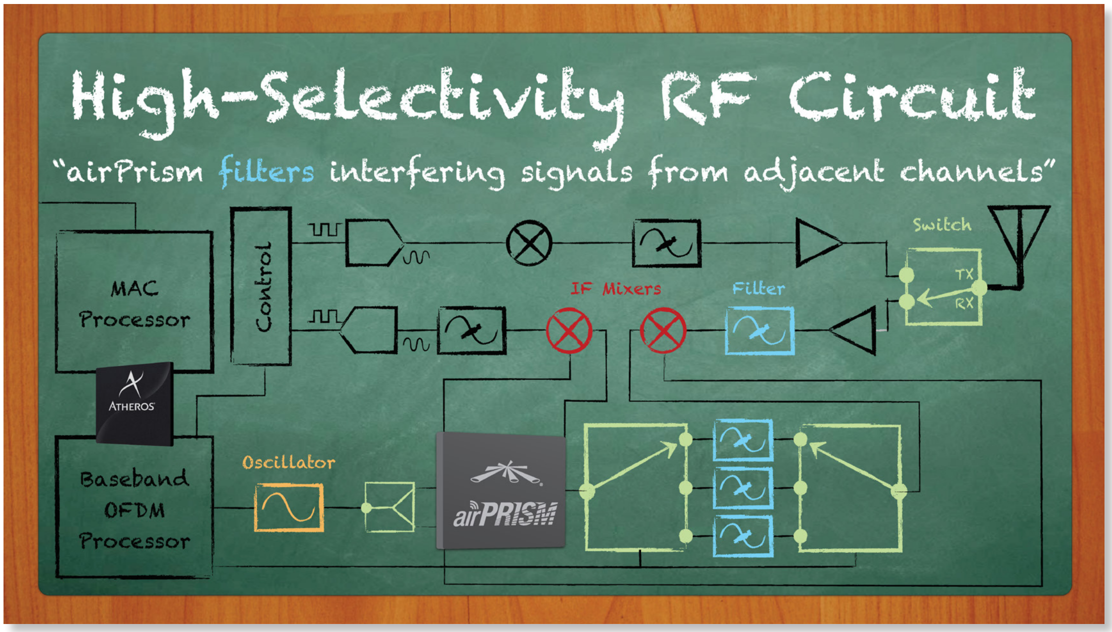
High Noise Environment

"Receiver's selectivity degrades in noisy RF environment"

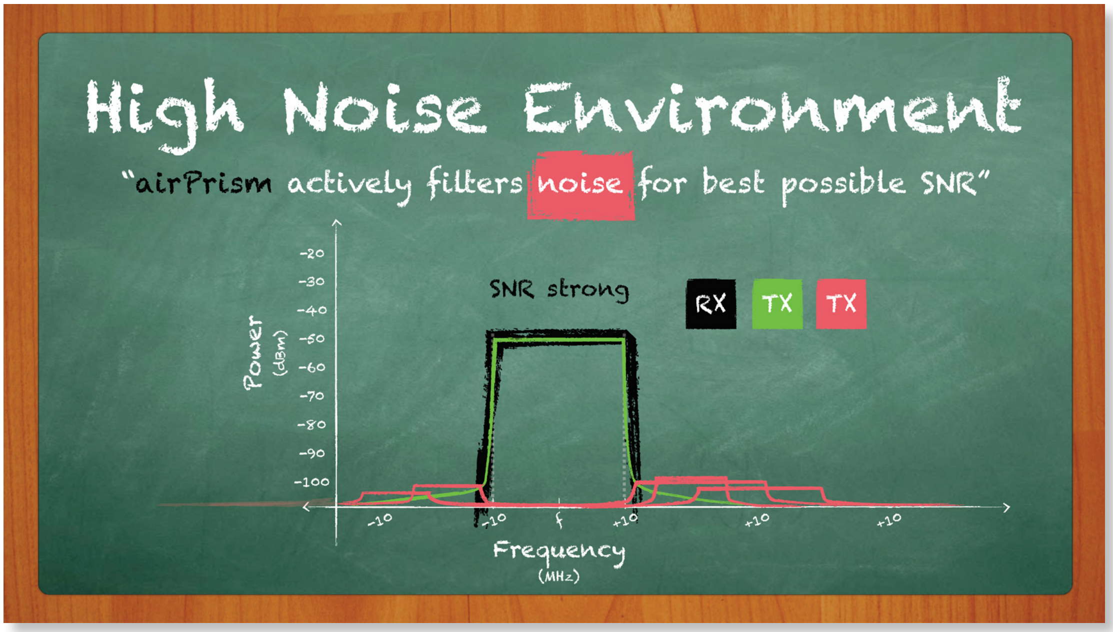
Radio operators can try to mitigate this issue through a number of techniques, including:

- **Spatial filtering**: By opting for higher gain antennas (more on this in the Antennas chapter).
- **RF shielding**: By introducing metal enclosures to block unwanted signals and minimize 'leaking' RF from radios/antennas.
- **GPS synchronization**: By simultaneously coordinating transmit/receive slots of neighbor radios to prevent **co-location interference**.

Although these actions may indirectly improve the performance the radio, they do not directly address the filtering inadequacies of typical 802.11 receivers. Ubiquiti's **airPrism active radio filtering** greatly reduces the amount of in-band, adjacent channel interference 'heard' by radios in noisy RF environments.



airPrism-equipped Ubiquiti radios feature a **high-selectivity RF circuit** in the front-end radio. In this HSR circuit, the carrier signal is downconverted to an **intermediate frequency** (IF), which better controls how the signal is filtered. By applying a channel select filter to remove the interfering signals, then upconverting the IF carrier signal, the baseband processor retrieves the 'cleaned' carrier signal.

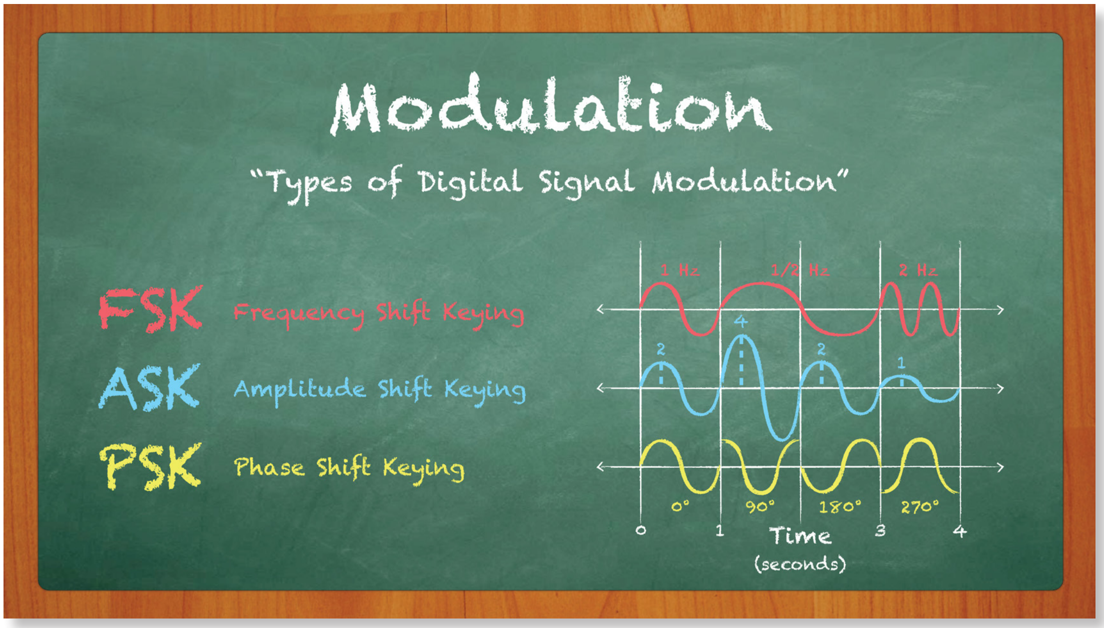


High Noise Environment

"airPrism actively filters noise for best possible SNR"

airPrism is very effective at filtering adjacent channel interference. Deploy airPrism-equipped radios in crowded RF environments for as much as 30+ dB of noise cancellation.

Modulation

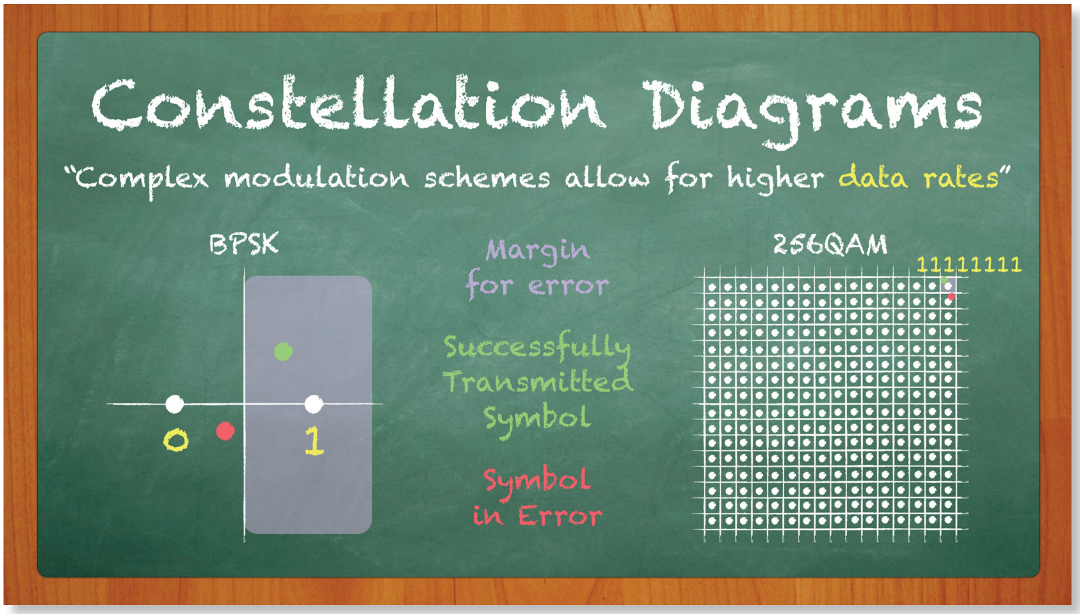


Modulation

"Types of Digital Signal Modulation"

Carrier signal modulation is the process by which a digital set of data (1's and 0's) are changed to/from carrier waveforms for purposes of wireless data transfer. Ubiquiti radios use discrete changes in the **phase** and **amplitude** of the carrier waveform to represent different groups of bits. When modulated, these bits are known as **symbol sets**. More complex modulation schemes yield a greater number of bits per symbol. In other words, more complex modulation schemes means higher maximum data rates.

Ubiquiti airMAX ac radios feature dedicated radio chipsets for tracking and monitoring the RF environment, including a real-time constellation diagram of local/remote receivers. **Constellation diagrams** provide a visual depiction of the performance of the receiver radio in accurately **mapping** symbol sets. This provides valuable insight into the robustness of the link in its current RF environment.

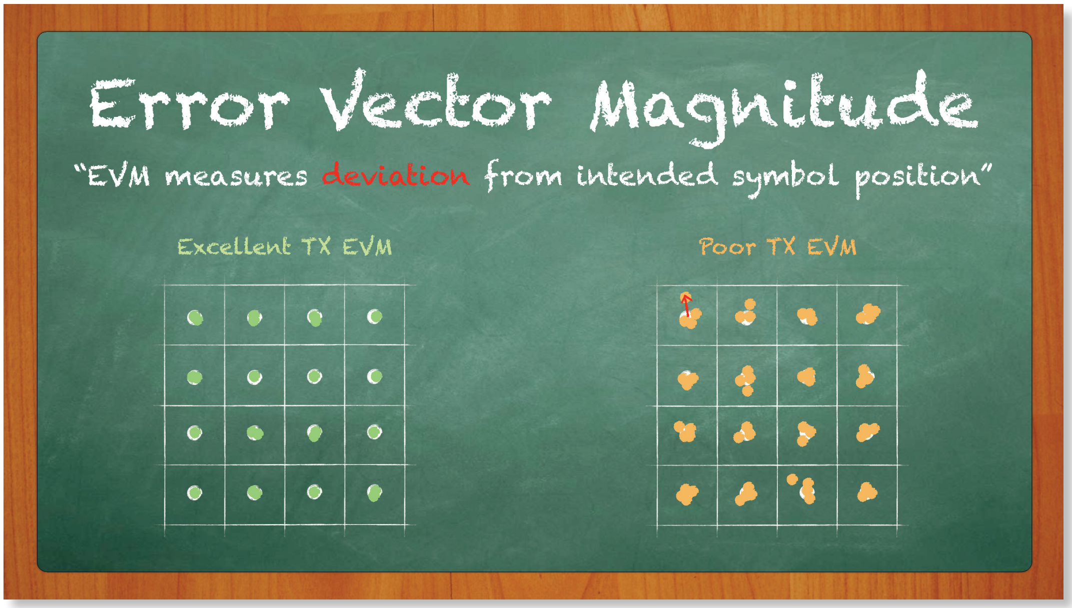


Constellation Diagrams

"Complex modulation schemes allow for higher data rates"

Error Vector Magnitude

The accuracy with which a radio codes/decodes these modulated signals is defined by its **error vector magnitude** (EVM). EVM measures the deviation of transmitted/received symbols from their intended position. If the symbol is properly mapped by the receiver, then the transmission is successful. If the symbol is incorrectly mapped by the receiver, then the transmitter must retransmit the symbol, often using a less complex modulation rate to compensate for intolerant noise levels. The more complex the modulation rate, the greater the SNR requirement.

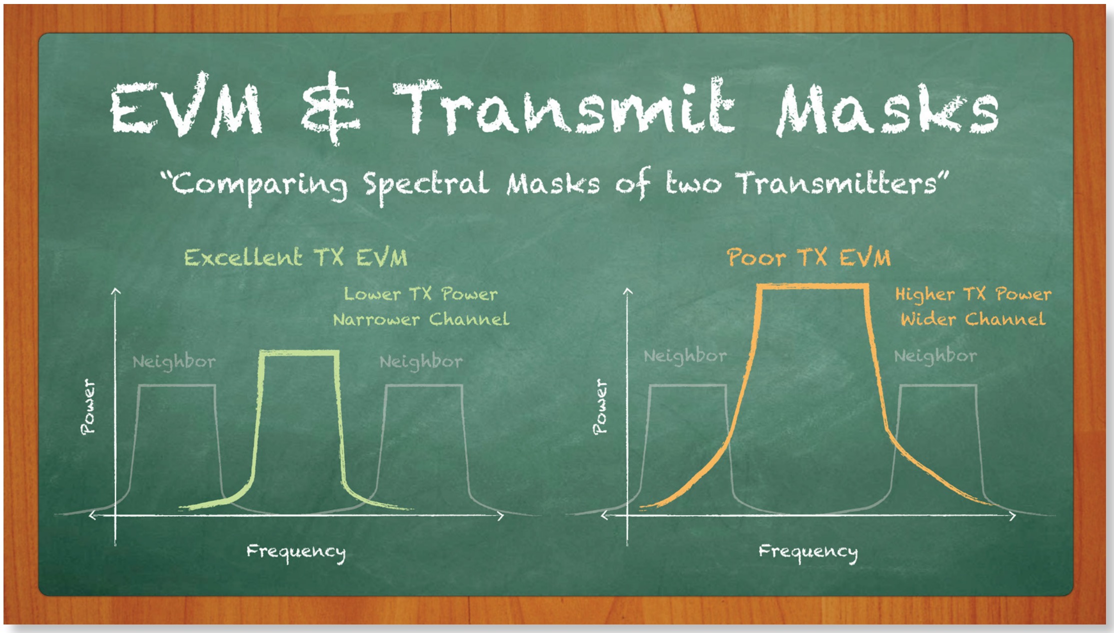


Error Vector Magnitude

"EVM measures deviation from intended symbol position"

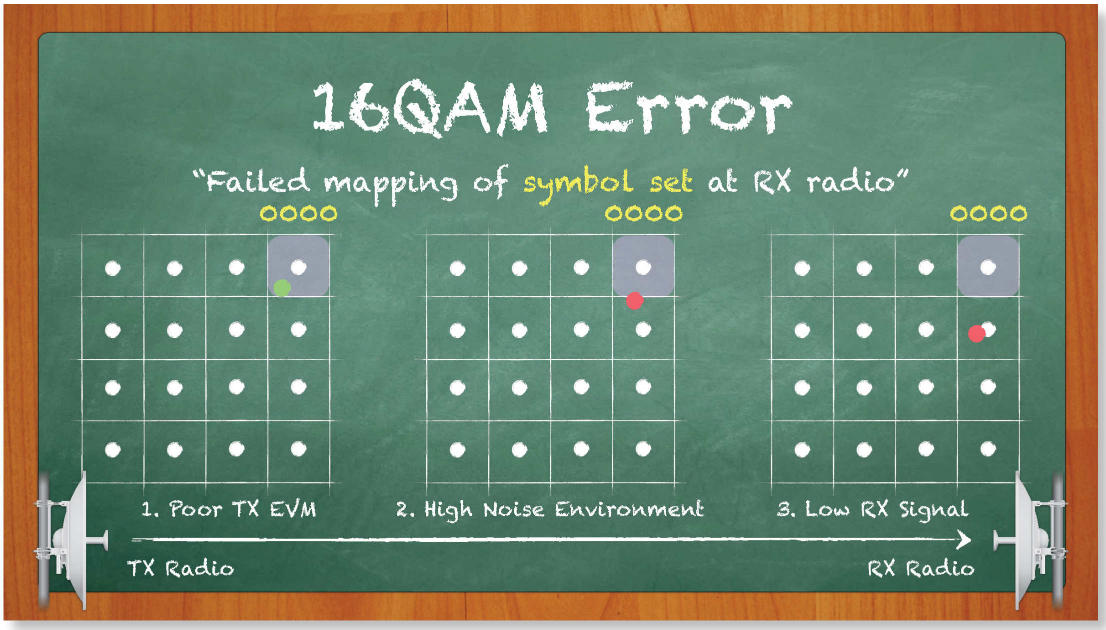
Ubiquiti airMAX and airFiber radios are powerful, fine-tuned devices with excellent EVM performance. Ubiquiti radios are rigorously tested in certified labs to ensure they operate according to expectations as defined by governing bodies such as the FCC. EVM performance is related to a number of important radio characteristics, including:

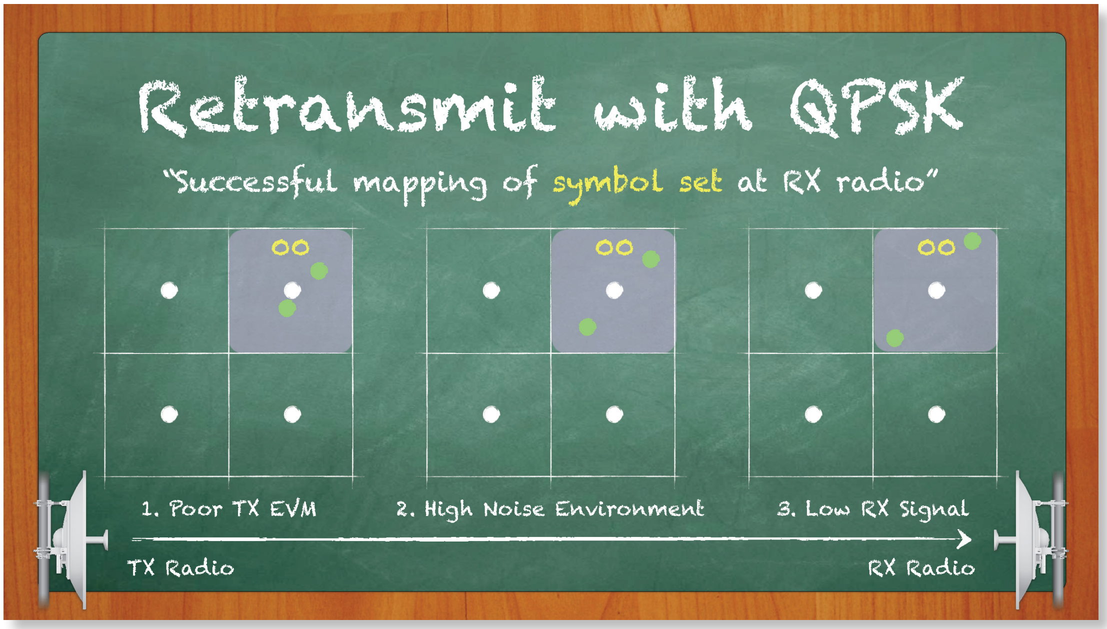
- **TX Spurs**: Undesired, spurious transmissions can occur as in-band or out-of-band emissions in poor EVM radios.
- **Harmonics**: As '**non-linear devices**,' all radios emit signals at multiples of the radio clock frequency. For example, an M900 radio set to operate 907 MHz will emit spurs at 1814, 2721, 3628, 4535, and 5442 MHz. Just as poor quality radios tend to suffer from spurious TX emissions, poor quality radios also exaggerate the emissions at harmonic-based clock frequencies. Although all Ubiquiti radios are high quality, carrier-class radios, the airFiber platform features the best cost-performance among all outdoor radios.
- **'Clean' Transmit Mask**: Poor EVM radios pollute the frequency band in which they transmit as they tend to have raised tail-ends. An excellent EVM transmitter has peak PSD across the channel with tail-ends that sharply drop off.



Modulation Process

The process by which two separate symbol sets are modulated (at the transmitter), propagated as a carrier waveforms (through free space), then demodulated (at the receiver) both improperly and properly is depicted in the following figure:





To automate and maximize the performance of the modulated radio circuit as much as possible, Ubiquiti radios use **probing** and **auto-adaptive** techniques. It is therefore recommended to leave the AUTO rate and maximum modulation levels selected. Between airFiber and airMAX radios, the following modulation rates are supported (listed by maximum data capacity, ascending):

- Binary Phase-Shift Keying (BPSK)
- Quadrature Phase-Shift Keying (¼ QPSK, ½ QPSK, QPSK)
- Quadrature-Amplitude Modulation (16QAM, 64QAM, 256QAM, 1024QAM)

Technical Documentation

Complete technical documentation for all of Ubiquiti's outdoor wireless products are published at **downloads.ubnt.com**, which contain information about supported modulation rates. The TX and RX Power Specifications section provides particularly important information relating to power levels and data rates.

The **minimum receive sensitivity** required for a given modulation rate assumes a 'clean' RF environment. Although **high TX power** is useful in propagating a signal across long distances, peak power levels can **saturate** or **distort** the carrier signal, leading to problems with EVM. Output power is therefore a limiting factor to which data rates are possible. However, **SNR** and **Channel Width** together determine which **Modulation** and **Data Rates** are possible, as explained by the **Shannon-Hartley Theorem**. Consult the appendices at the back of this manual to review the Modulation and Data Rates possible given a certain channel bandwidth.

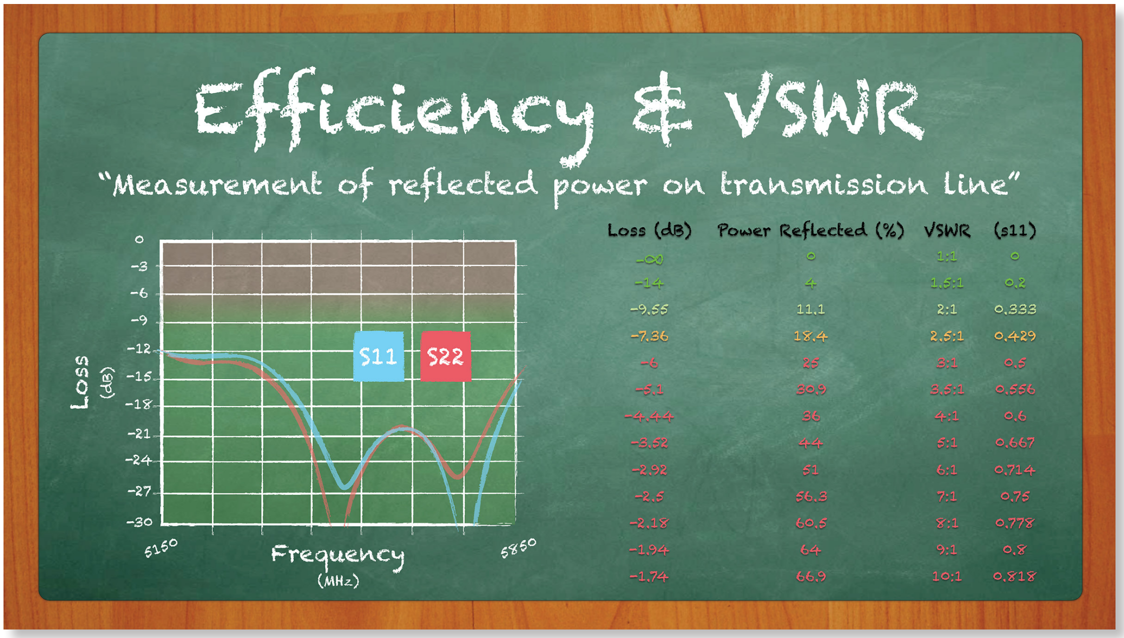
IV. Antenna Design

The second major part of any RF system is the antenna. When paired with a radio transmitter, the function of the antenna is to **convert energy** from the generated carrier signal into **radio waves**. When paired with a receiver radio, the job of the antenna is to convert radio waves back into electrical signals so the radio can decode information from the carrier. This chapter will explain the principal characteristics of antennas, presenting different antenna models for purposes of comparison.

Antenna Characteristics

Efficiency

One of the most important characteristics of the antenna is the efficiency with which it converts energy passing back and forth to the radio. **Voltage Standing Wave Ratio** (VSWR), otherwise known as **return loss**, measures the amount of energy that is reflected back and wasted on a transmission line (e.g., antenna feed, RP-SMA connectors) connecting the radio chain and antenna. Besides reducing the overall signal level, reflections can lead to radio delays and poor EVM performance.

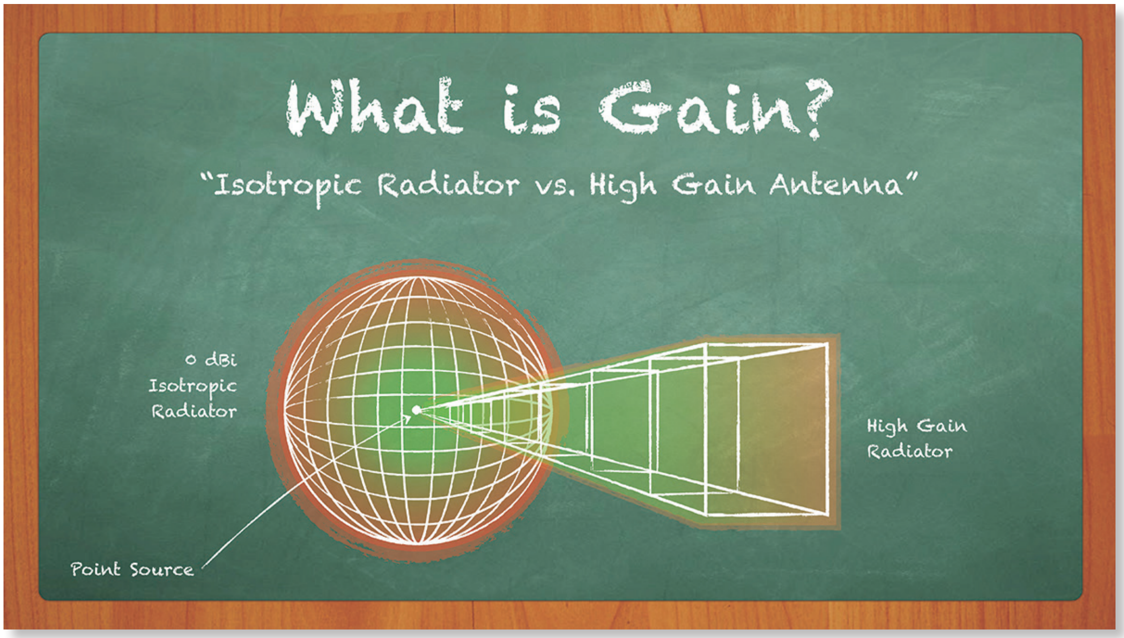


Loss (dB)	Power Reflected (%)	VSWR	(s11)
-∞	0	1:1	0
-14	4	1.5:1	0.2
-9.55	11.1	2:1	0.333
-7.36	18.4	2.5:1	0.429
-6	25	3:1	0.5
-5.1	30.9	3.5:1	0.556
-4.44	36	4:1	0.6
-3.52	44	5:1	0.667
-2.92	51	6:1	0.714
-2.5	56.3	7:1	0.75
-2.18	60.5	8:1	0.778
-1.94	64	9:1	0.8
-1.74	66.9	10:1	0.818

Return loss can be represented graphically by introducing **S-parameters**, where S11 represents the power passing between radio chain 1 and antenna 1. Likewise, S22 relates power passing from chain 2 to antenna 2. As return loss decreases from 0 dB (e.g., -3 dB, -6 dB), less power is reflected. VSWR of 1.5:1 or better represents an excellent performance transmission line (less than 4% loss).

Ubiquiti antennas are highly efficient devices—in some cases, 70% or more. In order to compensate for **losses** in **efficiency** and **FSPL**, antennas rely on gain.

Gain, Directivity & Size



What is Gain?

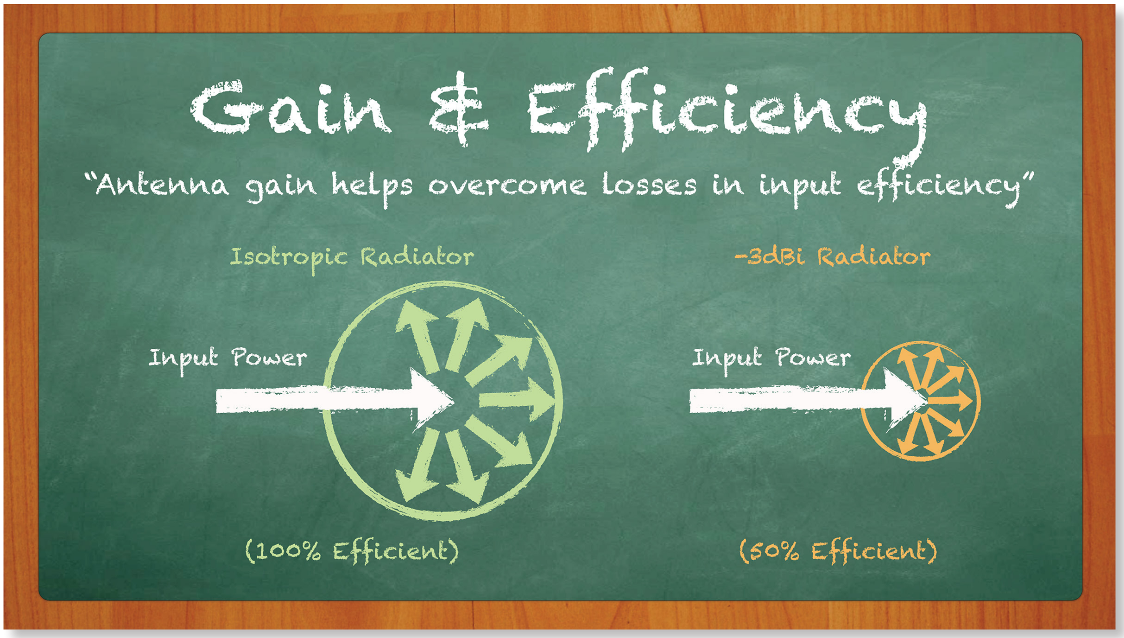
"Isotropic Radiator vs. High Gain Antenna"

0 dBi
Isotropic
Radiator

High Gain
Radiator

Point Source

Antenna gain measures the **efficiency** and **directivity** of an antenna. Directivity describes the direction and power density of the energy radiated by an antenna. Gain and directivity are often used interchangeably.



Gain & Efficiency

"Antenna gain helps overcome losses in input efficiency"

Isotropic Radiator

-3dBi Radiator

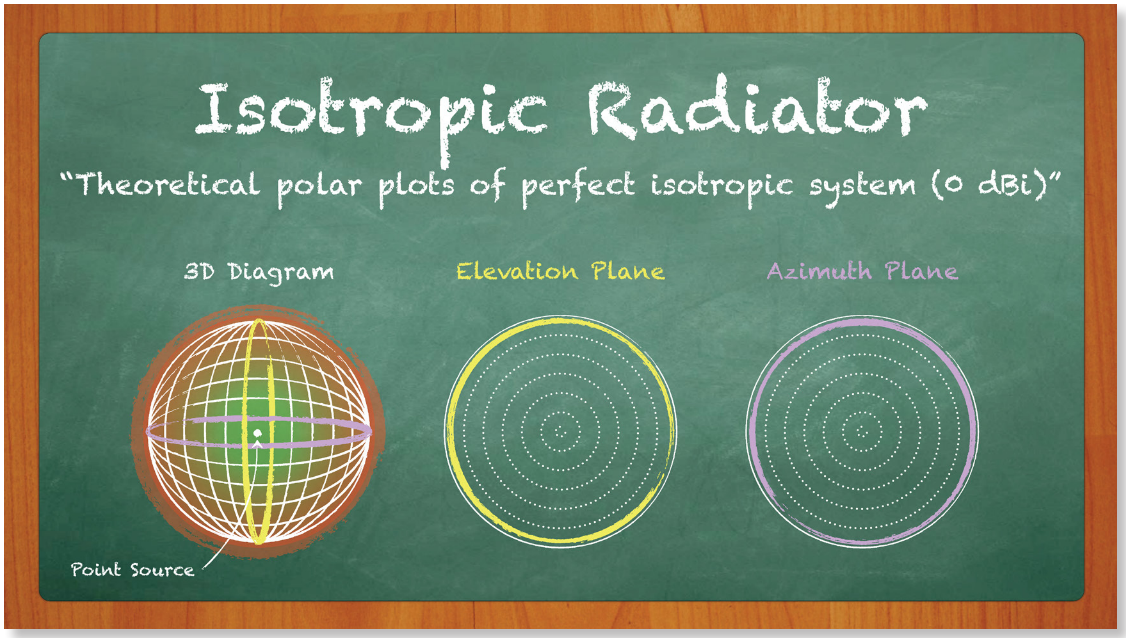
Input Power

Input Power

(100% Efficient)

(50% Efficient)

Like with radio power levels (dBm), antenna gain is measured using logarithmic units: **Decibels relative to Isotropic Radiator** (dBi). Antenna gain makes reference to a hypothetical **isotropic radiator** (0 dBi) that radiates from a point source in all directions equally with 100% efficiency. Although such a radiator does not exist, it would radiate in the shape of a sphere.



To increase the gain (directivity) of an antenna, **elements** are added to the antenna system. To increase antenna gain, more elements are added, which increases both the **size** and **directivity** of the antenna. A **high-gain antenna** is better-suited for long-distance PTP links than a **low-gain antenna**, since the high-gain antenna radiates the same signal into a more specific direction.

It is recommended that you use the **most directive antenna** for every scenario, whenever possible. Higher gain not only improves receive signals, but also increases **spatial filtering**. Spatial filtering represents an antenna's ability to 'focus' in a particular direction, which improves the SNR not only for the local receiver but for other nearby, in-band receivers.

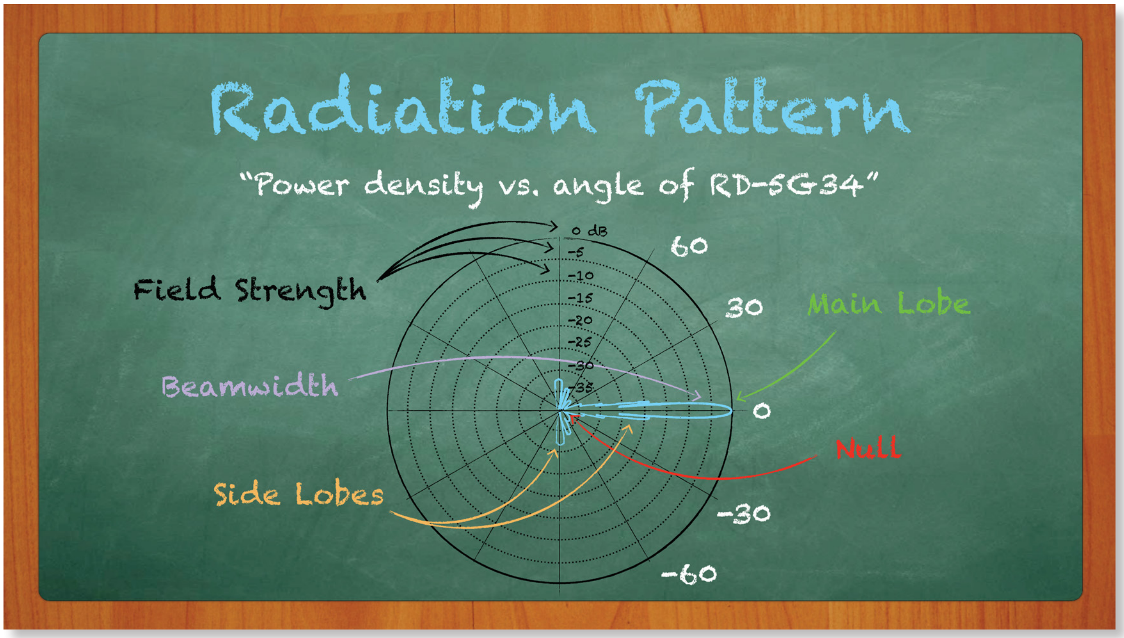
Antenna Reciprocity

Antenna reciprocity derives its name from the bidirectional effect that gain has on the receive signals (at both ends) of a wireless link. **Antenna gain** contrasts with **TX Power** and **RX Sensitivity**, two radio characteristics that only improve the receive signal in one direction. Not only does gain improve the RX signal at both sides of the wireless link, it also does so by an equal factor. This ensures a balance in bidirectional wireless performance.

Assume an already balanced PTP link has a receive signal of -50 dBm at both ends. Increasing the antenna gain at either end by 3 dBi will result in a receive signal of -47 dBm at both sides of the PTP link. This is due to the reciprocity of the antenna. Gain improves a station's ability to radiate and receive signals.

Radiation Patterns

Antennas radiate and receive signals across three-dimensional space, as represented by **radiation patterns**. Also known as **polar plots**, these patterns describe the power density and angle at which signals propagate from or are received by the antenna. Polar plots exist in two planes: **Azimuth** and **Elevation**. Together, these planes describe the three-dimensional radiation pattern of any antenna.



When installing an RF system, antennas require precise alignment along the angle at which peak power density is radiated, otherwise known as the **main lobe**. When properly aligned, the antenna improves the receive signal by a factor equal to the gain level. If improperly aligned however, the receive signal will drop by a factor equal to the density and angle of the lobe (known as **side lobes**) on which the antenna is aligned. The main lobe corresponds to the peak power (0 dB) measurement, which for carrier antennas, lies at the 0° mark. To measure the gain of an antenna at a given angle, including a side lobe, trace the pattern back to the line of **field strength** (e.g., -3/-5/-10 dB) to which the polar plot corresponds. **Nulls** represent the areas where no power is radiated.

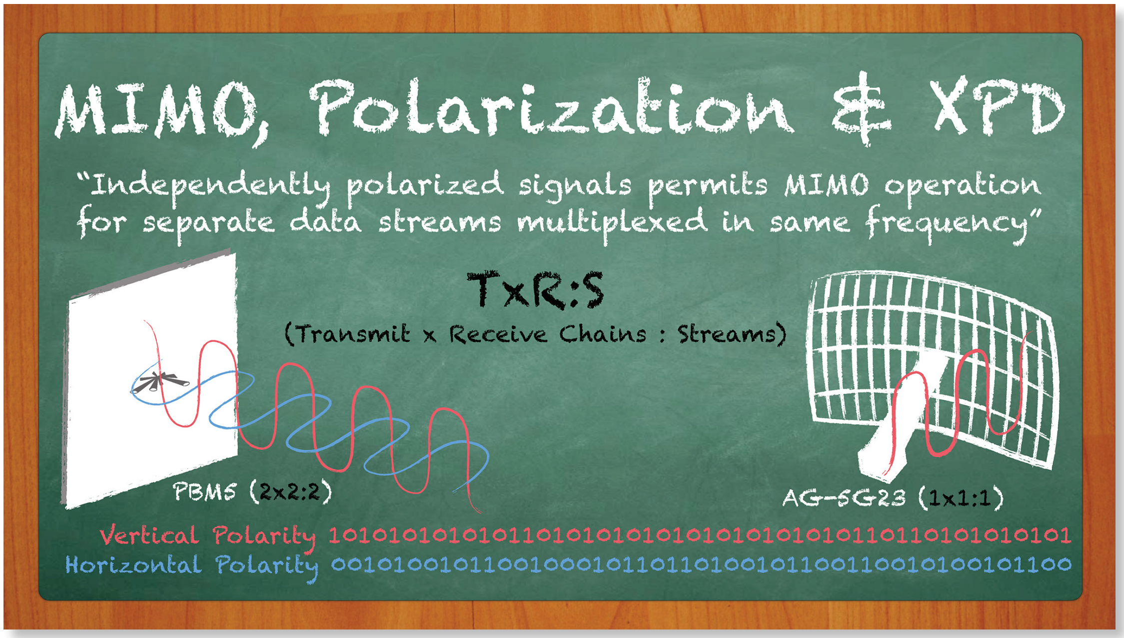
Despite achieving a wireless link with antennas aligned to the side lobes, there can be even greater consequences beyond simply a weaker-than-expected receive signal. Because the main lobe is misaligned, the peak power level is now radiated in an unintended direction. If another in-band RF system (e.g., neighbor radio links) should lie in this main lobe, the misaligned antenna could negatively impact its SNR.

Among Ubiquiti's link planning tools, the following should always be used when planning and installing a new wireless link:

- **Ubiquiti Link Simulator**: Used to accurately estimate the receive signal.
- **Site Survey**: Used to monitor the level at which competing, in-band networks are 'heard' by the RF system.
- **airView**: Used to monitor energy levels from all EMI sources across the entire spectrum.
- **Antenna Alignment**: Perform to achieve the estimated signal based on Link Budget estimates.

Antenna Polarity

All electromagnetic waves travel through space consistent with a given plane, or, **polarity**. Ubiquiti antennas are **linearly-polarized**, meaning they radiate waveforms along distinct planes: vertical (**V-pol**) and horizontal (**H-pol**). Signal polarization is another reason why antennas must be properly aligned, since a **polarity mismatch** at either end would result in a **loss of signal intensity**.



For example, a 5 GHz signal travels toward a receiver along the vertical polarity. For this signal to be perfectly 'heard,' the receiver's antenna must be exactly aligned to the vertical plane. If the receiver's antenna was shifted even 1° outside this polarity, then the signal would be 'heard' with less intensity by the receiver.

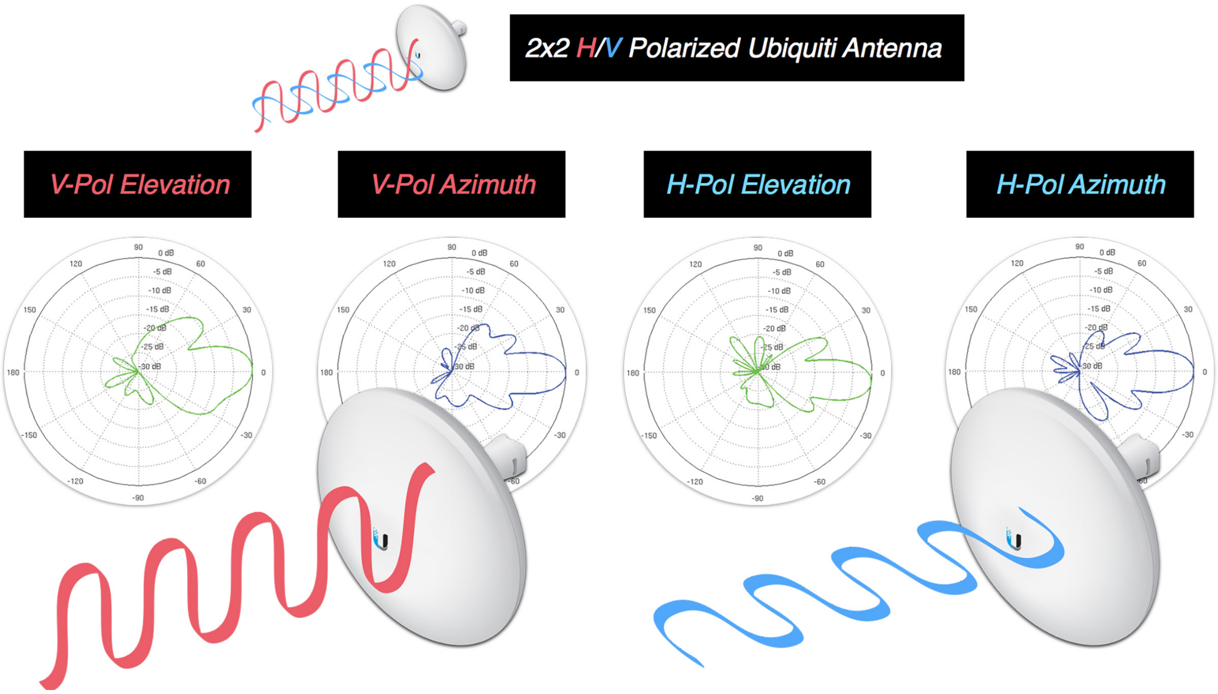
If the same receiver antenna were shifted 90° from the vertical polarity, then the receive signal would in theory no longer be 'heard'. This is because the receiver antenna is now completely polarized along the horizontal plane. The receiver will therefore 'hear' 5 GHz signals arriving along the horizontal plane.

Signal polarization is very useful in wireless networking. Separately polarized signals allow for **Multiple-In, Multiple-Out** (MIMO) operation, where a transmitter sends **multiple spatial streams** in the **same frequency band** to a receiver for increased data capacity. Each polarity (e.g., **V-pol** / **H-pol**) corresponds to a given radio chain (e.g., Chain 0 / Chain 1). When properly aligned, the receive signals across both chains should be very close to equal (e.g., -50 / -49 dBm). A signal mismatch greater than 3 dB may indicate a problem with the line-of-sight of the wireless link (e.g., scattering, reflections).

MIMO operation is typically expressed in the format TxR:S, with the following variables:

- **T**: The number of **TX Chains**.
- **R**: The number of **RX Chains**.
- **S**: The number of supported **Spatial Streams**.

Each radio chain is associated with a separate antenna. The number of polar plots is dependent on the number of spatial streams. For example, a 2x2:2 device like the NBE-5AC-19 has a total of four polar plots—one azimuth and one elevation plot for both H-pol and V-pol chains, respectively, as demonstrated by the following figure:

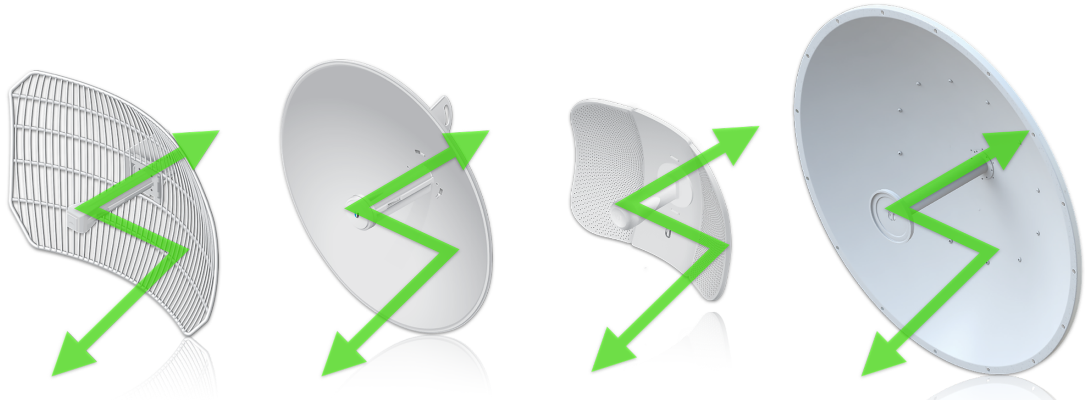


Because the elements of an antenna are never totally polarized in a given plane, **cross polarization discrimination** (XPD) is an especially important characteristic that represents the ability of the antenna to separate the two polarities. Ubiquiti antennas feature XPD as high as 35 dB. XPD and other properties are listed on Ubiquiti's antenna datasheets, available at downloads.ubnt.com.

Types of Antennas

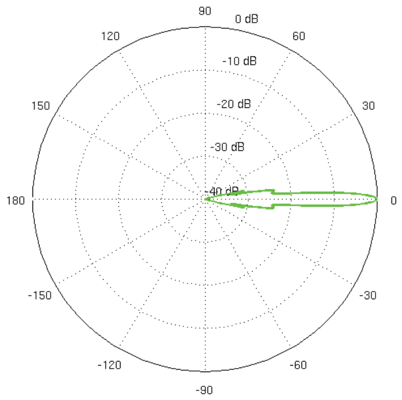
In this section, you will explore the different kinds of antennas made by Ubiquiti, including the scenario in which they should be used and advice for installation.

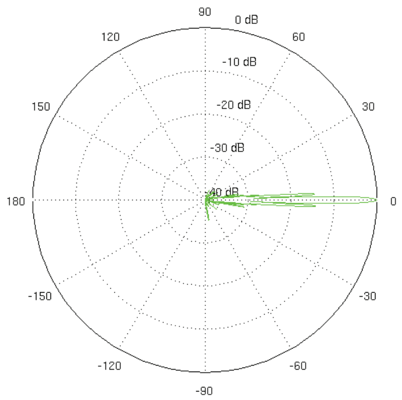
Dish Antenna



TX/RX Signal & Grid/Dish Reflector

Parabolic reflector, or more commonly, '**dish**' antennas are high gain, high directivity devices. A dish antenna is composed of two pieces: **feedhorn** and **reflector**. Both are positioned such that the reflected waves are in-phase and add together to produce gain. Energy passes between the feedhorn and the radio, reflecting off the dish to produce a highly directive radiation pattern, not unlike the following TX and RX polar plots for AF24.

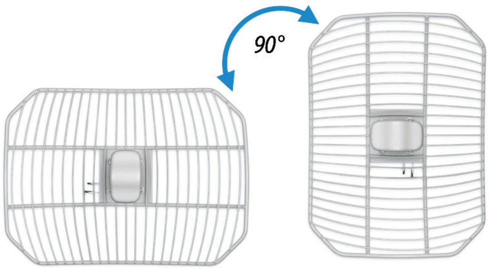




Ubiquiti manufactures several high gain, high efficiency dish antennas that are commonly deployed in high performance PTP links (e.g., RD-5AC-31) and as long-distance CPEs (e.g., PBE-5AC-500). **airFiber antennas** feature a **45° dual-slant design** that increases the isolation from typical linearly-polarized antennas (e.g., H-pol, V-pol) by as much as +3 dB. When occupying the same frequency band (e.g., 5 GHz), it is recommended to deploy PTMP networks on standard polarities and PTP links on slant polarities. Antennas with slant-design are also beneficial to outdoor wireless networks since they tend to have **propagation** and **multipath performance**.

Grid Antenna

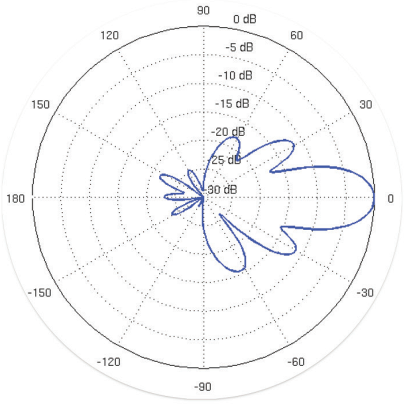
Grid antennas function similar to dish antennas, relying on a feedhorn and **grid** reflector apparatus to propagate and receive signals. Despite their advantageous form factor and **wind-loading** capabilities, Ubiquiti grid antennas are **Single-In, Single-Out** (SISO) devices. This confines the radio to 1x1 operation, which results in half the maximum data rates of their 2x2 counterparts. The linear polarity of 1x1 antennas like Ubiquiti airGrid and LiteBeam can be changed by rotating the antenna 90°. In this way, two 1x1 devices can occupy the same frequency channel (e.g., 5800 MHz) without directly interfering.

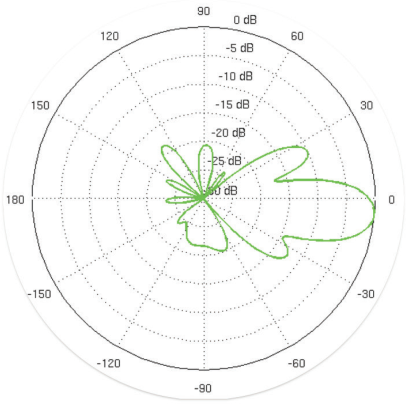


Vertically-Polarized *Horizontally-Polarized*

Panel Antenna

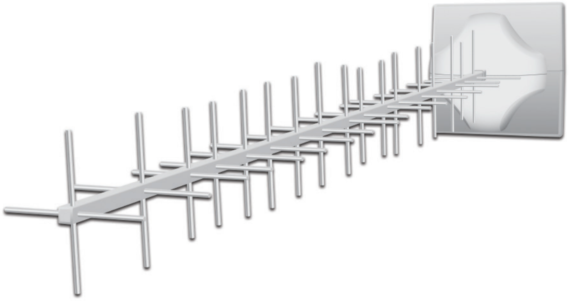
Panel antennas (also called **patch** antennas) split power across multiple metal elements, often along a metal panel or PCB. The radiated signal from each element combines in phase to increase the directivity of the antenna. Ubiquiti panels like **NanoStation**, **NanoBeam**, and **PowerBridge** have a simple, integrated radio and antenna design. Although the overall pattern will depend on each individual antenna, the **NBE-5AC-19** polar plots that follow show the radiation pattern for a typical panel antenna used at short ranges for CPEs.





Yagi Antenna

Yagi antennas offer good directivity and are common in PTP links. The AMY-9M16 is ideal in rural areas since 900 MHz signals propagate well in **non-line-of-site** (NLOS) scenarios. The radiated signal reflects off **director elements**, which together, produce a pattern not unlike that illustrated in the following polar plots.

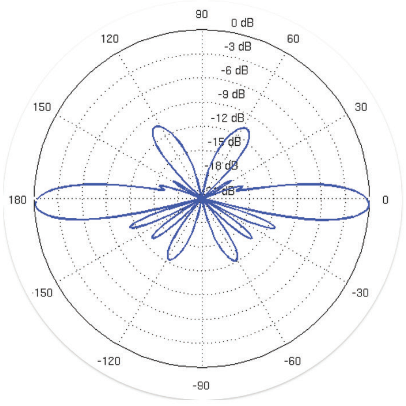


Omni Antenna

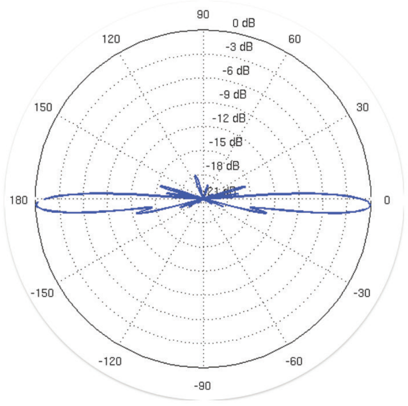
Omnidirectional, or **omni** antennas, provide 360° of coverage on the azimuth plane. They are typically used in outdoor wireless networks where universal coverage is needed, like APs at base station tower sites. Despite affording ease of deployment, their range is relatively short. Because omni antennas radiate in 360°, they lack adequate **spatial filtering** needed in environments with increased noise levels. Be careful when deploying omnidirectional antennas since they quickly pollute the immediate vicinity for in-band radios on separate networks. As previously mentioned, the most directive antenna for each individual scenario is always recommended.

While all omni antennas offer 360° coverage on the horizon, higher gain omnis provide increased range. In the following example, compare the elevation planes of two 5 GHz omni sectors: 10 and 13 dBi, respectively. Due to its higher gain/directivity, the 13 dBi model features narrower main lobes along the 0 and 180° markings.

AMO-5G-10

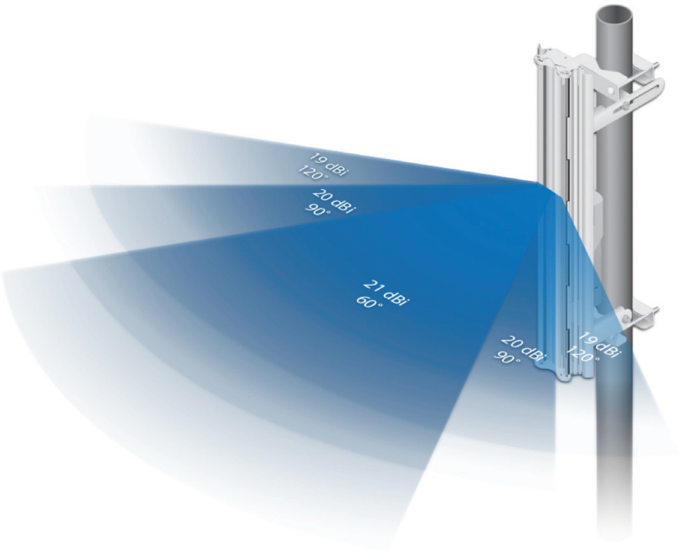


AMO-5G-13

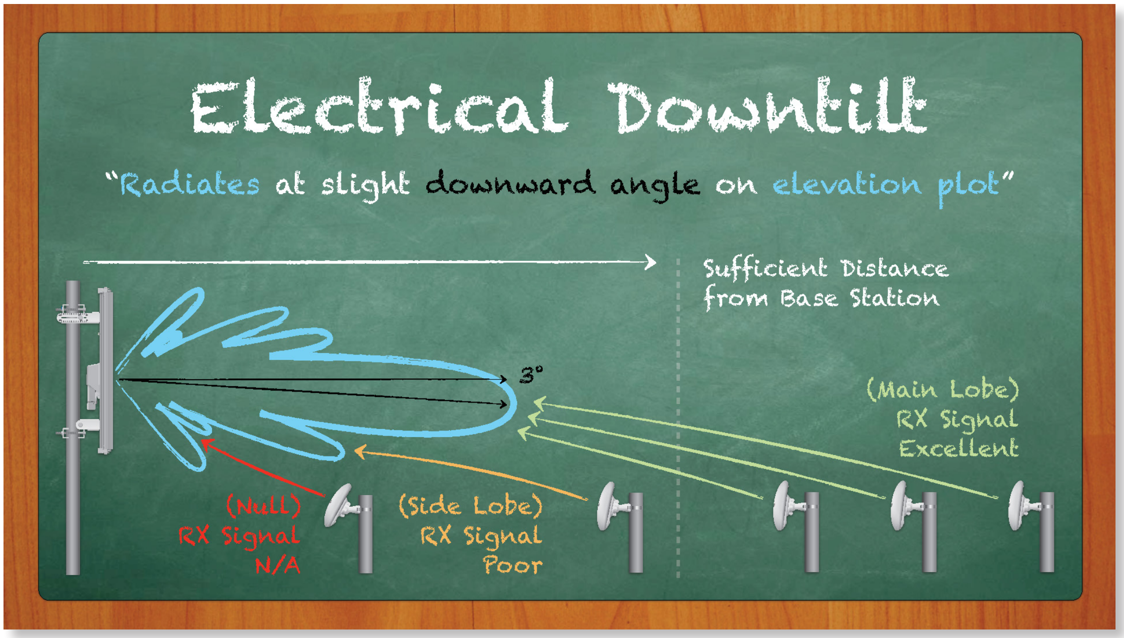


Sector Antenna

Compared to omnidirectional antennas, **sector** antennas are more directive devices. Sector antennas provide a set amount of coverage on the azimuth plane as defined by their main lobe **beamwidth**. airMAX sector antennas have beamwidths commonly divisible by 15° (e.g., 45°, 60°) in order to provide cumulative, 360° coverage at base station tower sites. Compared to omni antennas, a **cluster** of three or more airMAX sectors can provide complete coverage across **greater distances** and with much **better spatial filtering**. Cluster radio networks are also beneficial since they support a higher total of supported clients per AP.



airMAX sector and omni antennas feature built-in **electrical downtilt**. This property introduces a slight (usually 2-4°) downward angle at which energy radiates from the sectors, visible in the **elevation** polar plot for a given sector/omni antenna. Electrical downtilt is useful since, in most cases, the AP is positioned higher than the clients. The signal from the main lobe reaches clients along a trajectory whose distance may be calculated. Clients too close to the tower may lie outside the trajectory of the main lobe. Instead, clients lying in the **nulls** or **side lobes** of the radiation areas ‘hear’ a signal weaker than expected.



Despite radiating most power in the direction of the intended receivers, some energy can '**leak**' out the back and sides of an antenna, as noted by an antenna's radiation diagrams. Ubiquiti antennas feature high **front-to-back ratios**, particularly, **airMAX ac** and **airFiber** antennas. These properties are important when scaling the radio network, as co-located antennas in close proximity can introduce new interference challenges (to be explored in the next chapter).

V. Ubiquiti Service Providers

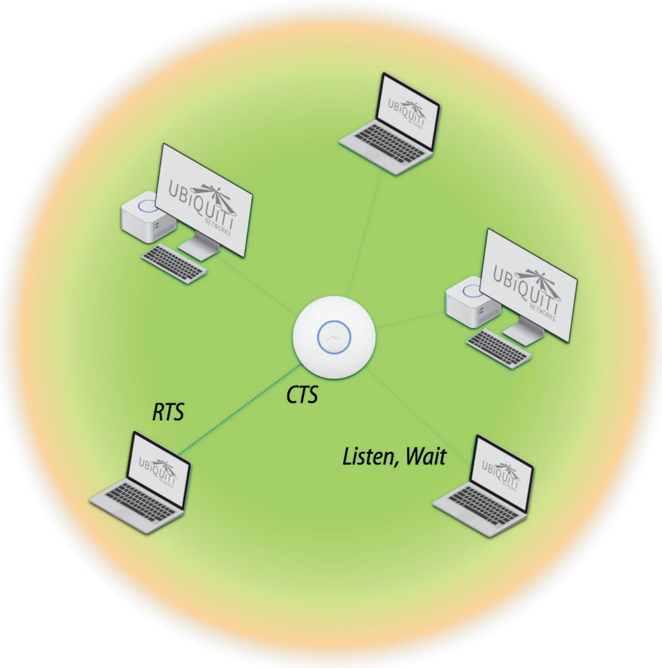
Ubiquiti's outdoor wireless platforms continue to revolutionize the WISP industry. Simple to use and configure, powerful and high performing, yet cost-effective in the market, both airMAX and airFiber continually raise the standard for service provider outdoor radio networks. Throughout this chapter, descriptions and techniques for designing the best possible WISP network will be explored.

airMAX PTP & PTMP Systems

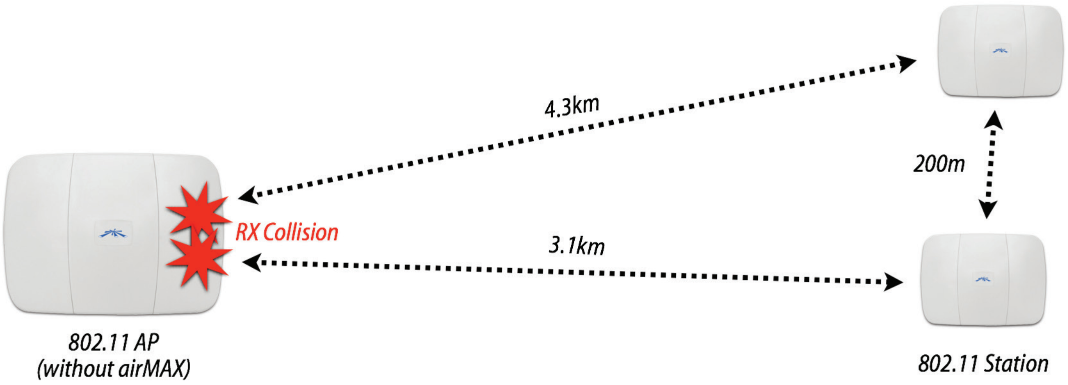
airMAX is a reliable, high-performance wireless protocol developed by Ubiquiti's expert software engineers while working in close collaboration with hardware teams. Built on the latest 802.11 technology standards for the best possible speeds, airMAX implements a proprietary access method so WISP networks can scale without limiting performance.

TDMA Solution for 'Hidden Nodes' & Scalability

airMAX works differently from conventional wireless access methods like UniFi. UniFi and other 802.11-based wireless systems operate according to **Carrier-Sense Multiple Access, Collision Avoidance** (CSMA/CA). Whenever a wireless station (radio) needs to use the channel, it listens prior to transmitting. If the channel is occupied, whether by a competing network or by a station on the wireless network, it will initiate a random timer countdown before listening again. If the channel is unoccupied, then the station will transmit.

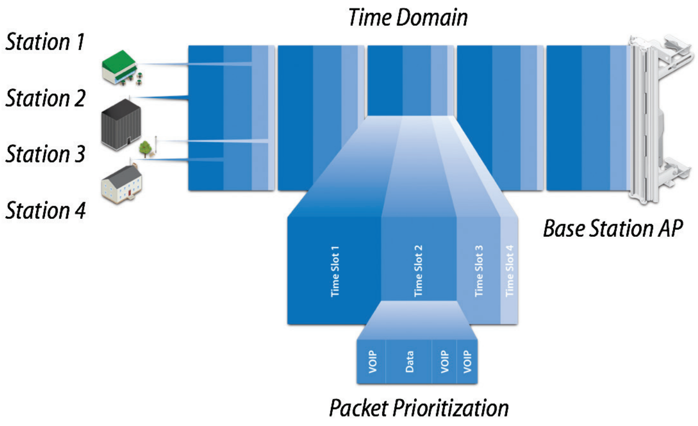


Intended for indoor environments, CSMA/CA typically performs well since wireless stations are all in close proximity of one another. In outdoor wireless however, CSMA/CA scales poorly, due to the nature of high-gain antennas and long distances between clients. Unable to ‘hear’ each other, these clients, or **hidden nodes**, may listen and transmit simultaneously, resulting in a ‘**receive collision**’ at the AP. As more hidden nodes join the AP network, more ‘collisions’ occur, which causes speeds to decrease and latency to increase.



Instead, Ubiquiti implements a proprietary **Time Division Multiple Access** (TDMA) method. The AP divides the wireless channel into time slots, designating pre-determined time intervals for each connected station. This prevents two or more connected stations from transmitting at the same time, thus eliminating ‘collisions’ at the AP.

Ubiquiti’s airMAX protocol also keeps track of which stations are active, splitting airtime among these stations. For example, idle stations may have dedicated time on the AP and not use it; the TDMA protocol redistributes the dedicated time to active stations so that airtime is not wasted.



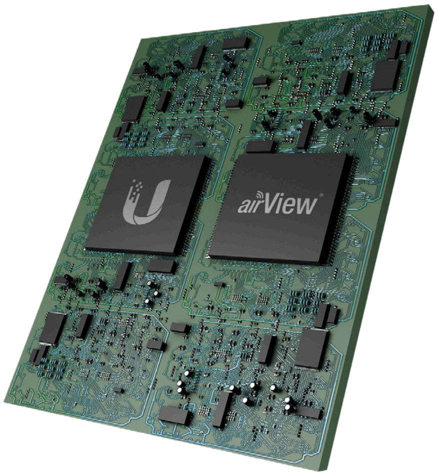
Intelligent QoS

The airMAX protocol supports intelligent **Quality of Service** (QoS), where latency-sensitive packets containing VoIP and video data receive priority. The AP inspects packets and prioritizes based on markers as defined by the **Wireless Multimedia Extensions** (WME) standard (listed in the appendices of this manual). Automatic QoS-based prioritization differs from manual airMAX priority overrides, which will be discussed later in this chapter.

Latest Technology & 802.11 Hardware

airMAX products support the 802.11 standards for wireless networking. The latest generation of airMAX radios are based on 802.11ac, the previous generation, 802.11n. Compared to its predecessor, 802.11ac achieves greater wireless data rates, through a number of improvements, including:

- Greater Channel Width (40 to 80 MHz)
- Higher Order Modulation (256QAM—up to MCS9 per chain)
- Improved PHY/MAC Efficiencies



Even when negotiating at 802.11n data rates, airMAX ac radios often permit higher throughput. And while airMAX M and ac radios use similar chipsets, airMAX ac products feature faster processors as well as a dedicated **airMAX co-processor**. Besides assisting with the TDMA protocol, the airMAX ASIC engine also powers a second, dedicated radio, which persistently analyzes the radio spectrum (airView) and every received symbol (constellation charts).

airFiber PTP Systems

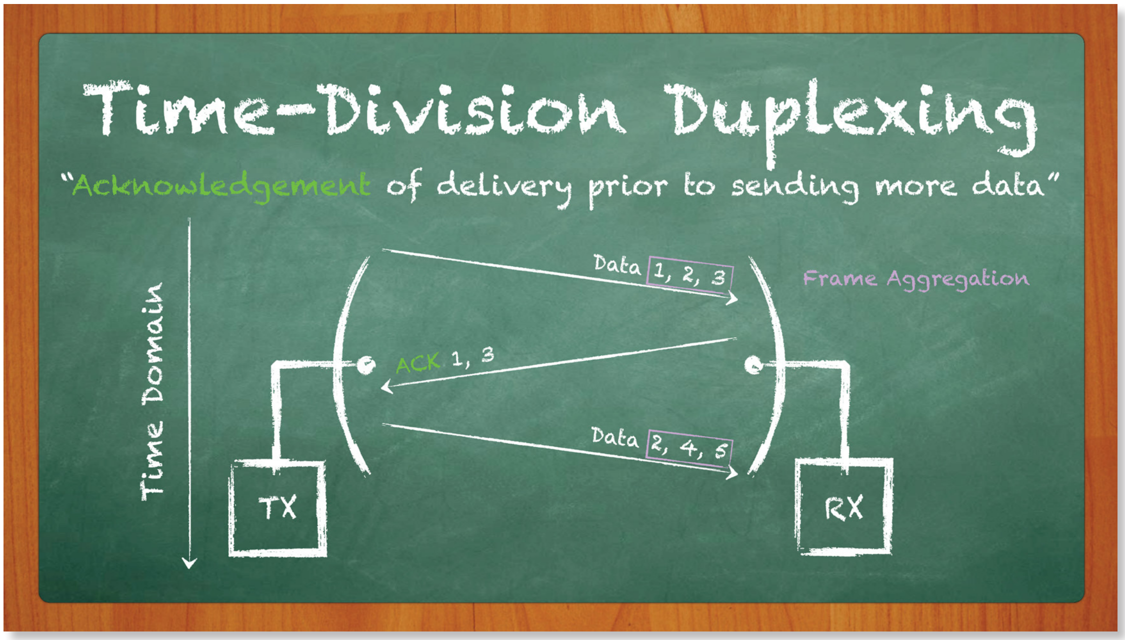
airFiber is a high performance backhaul solution for service providers worldwide. Compared to the 802.11 'Wi-Fi' radios deployed in most of today's wireless networks, airFiber features a completely proprietary hardware architecture, both designed and built by Ubiquiti's own engineers. Powered by Ubiquiti's **INVICTUS** engine, the key RF components are outlined below:

- **Custom Silicon** for modding and to eliminate RF loss with connectors and on-board components, increasing RF sensitivity and link budget potential.
- **Zero IF Radio**, which avoids intermediate frequencies and further improves spectral efficiency and co-location ability.
- **Unique MAC & FPGA** that optimizes packet processing at the hardware level, reducing latency to the lowest possible levels seen in backhaul links.
- **MIMO Design**, further enhancing signal processing and multiplexing, while maximizing sensitivity, SNR, and throughput.

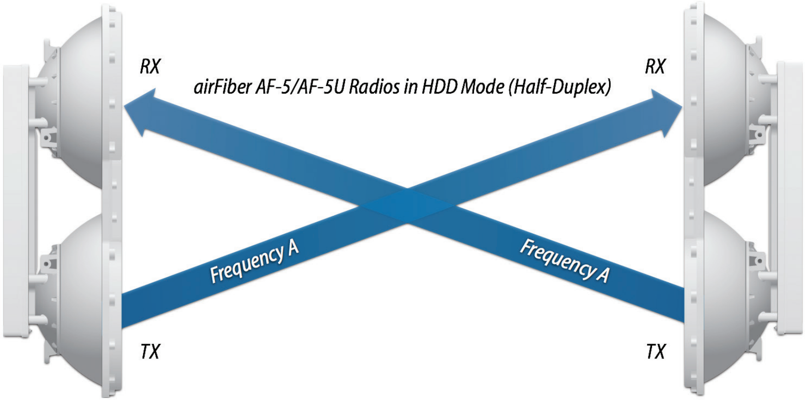
airFiber is the result of the cumulated and continual work of Ubiquiti's expert team in developing a purpose-driven platform. Compared to the 802.11 "Wi-Fi" based chipsets prevalent in today's WISP market, airFiber provides industry leading performance without compromising spectral efficiency. Depending on the conditions and requirements for your deployment, you can choose between two **radio modes** for your airFiber wireless links.

Hybrid-Division Duplexing

Hybrid-Division Duplexing (HDD) is a patented Ubiquiti technology that improves the efficiency of the **Time-Division Duplexing** (TDD) protocol. Despite its reliability and widespread use in both indoor and outdoor wireless networks, TDD systems face inherent delays from added overhead traffic and increased airtime usage. TDD systems like 802.11 'Wi-Fi' require **acknowledgement** of delivery (**ACK** frames) prior to sending more data, as illustrated by the following figure:



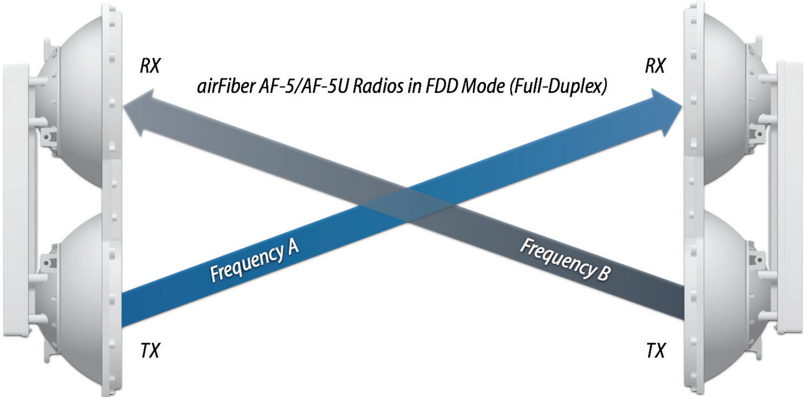
airFiber avoids the delays of conventional TDD by utilizing its patented, **adaptive synchronous protocol**, HDD. Through HDD, the **master airFiber node** synchronizes with the **slave node** using common time clocks and scheduled traffic loads. With precise timing, the slave node can begin transmitting before the master has finished transmitting, and vice-versa. In this way, HDD is a **half-duplex** protocol, capable of using one or two wireless channels. HDD mode is recommended for its robustness for environments that experience high levels of **reflectivity** or **scattering** (e.g., heavy rain, foliage). HDD is also particularly well-suited for long distance links.



While in half-duplex mode, the **master** airFiber unit can be configured with custom **TX duty cycles** in scenarios where the flow of bandwidth is disproportionate with respect to the TX/RX direction. By default, the master unit's TX duty cycle is 50%, meaning, equal time is spent transmitting and receiving data on the master airFiber unit. If the ratio of TX to RX data is 2:1, meaning the master airFiber radio transmits twice as much data as it receives, then the TX duty cycle should be set to 67% for maximum efficiency.

Frequency-Division Duplexing

Compared to HDD, **Frequency-Division Duplexing** (FDD) is a **full-duplex** protocol. Using two separate wireless channels and a split antenna architecture, both master and remote airFiber nodes transmit and receive concurrently, in real-time. As an efficient protocol, FDD achieves the highest possible throughput with lowest possible latency. Despite its potential, FDD mode is particularly susceptible to reflections and scattering. FDD also performs best in shorter distance links.



Design, Deployment & Management Tips

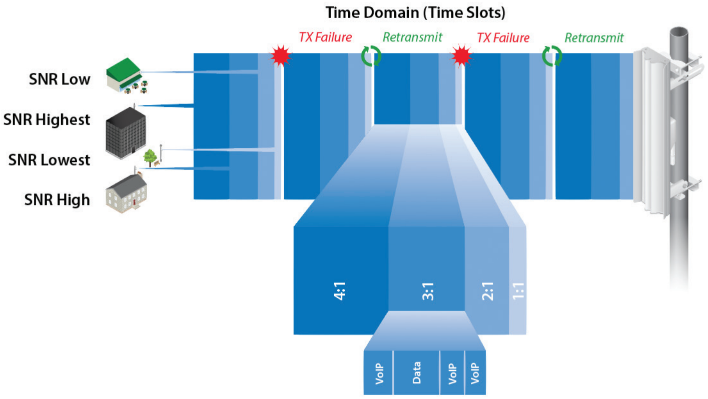
Airtime, Weakest Link, and airMAX Priority

Airtime is an important metric relating the data efficiency of a wireless station. Expressed as a percentage, airtime relates the average wireless bandwidth usage as a percentage of the maximum theoretical bandwidth utilization. Airtime is shared among all stations participating in the **AP cell**, or the wireless network. The larger the cell, the less airtime available for each individual station. Although airMAX PTMP APs support as many as 100+ active stations, multiple, **smaller cell sizes** are preferred since they ensure that the best possible signals arrive at receivers.

The airMAX protocol efficiently assigns time slots to active stations, so inactive stations do not waste airtime. When the airMAX network is nearing maximum capacity, try to identify the stations using the most airtime and improve their SNR through use of higher performance equipment (e.g., higher gain antenna). With higher SNR, the station can achieve higher maximum data rates, meaning it uses less airtime to send the same amount of data.

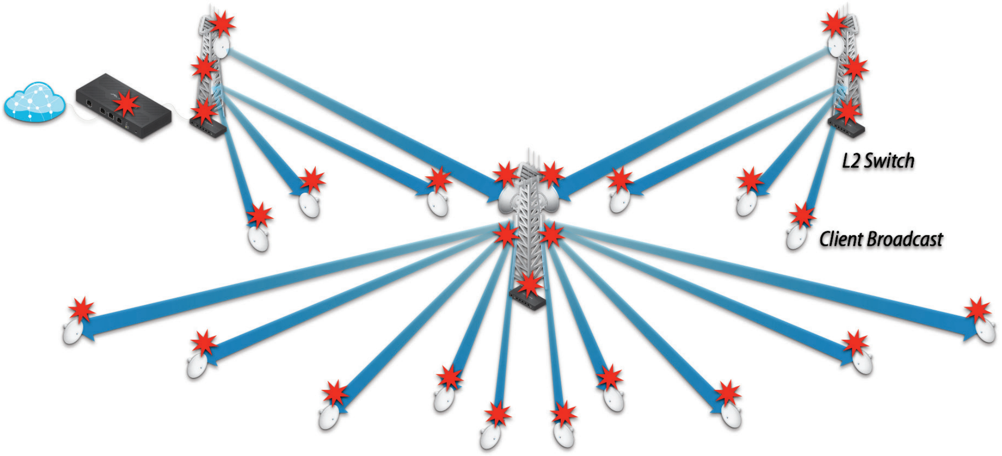
In PTMP scenarios, stations with **poor signal levels** routinely bring down the rates of the **aggregate** (overall) network. This is because stations with poor SNR consume more airtime to send the same amount of data. Also known as the '**weakest link**,' a single poor SNR station can jeopardize the aggregate performance of the entire PTMP network (as illustrated by "Station 3" in the following diagram). After exhausting every physical solution to improve the SNR of a 'weakest link' client, the airMAX protocol implements software controls in order to give channel access priority to strong SNR clients. In airOS-8 and later, the airMAX priority algorithm is handled automatically by the software protocol. In airOS-7 and earlier, operators can override time slots for clients according to their SNR, where high SNR clients receive 'high' time slot ratios; poor SNR clients, 'low.'

- High (4:1, reserved for clients with best / highest SNR)
- Medium (3:1)
- Base (2:1, the default ratio)
- Low (1:1, reserved for clients with poorest / lowest SNR)

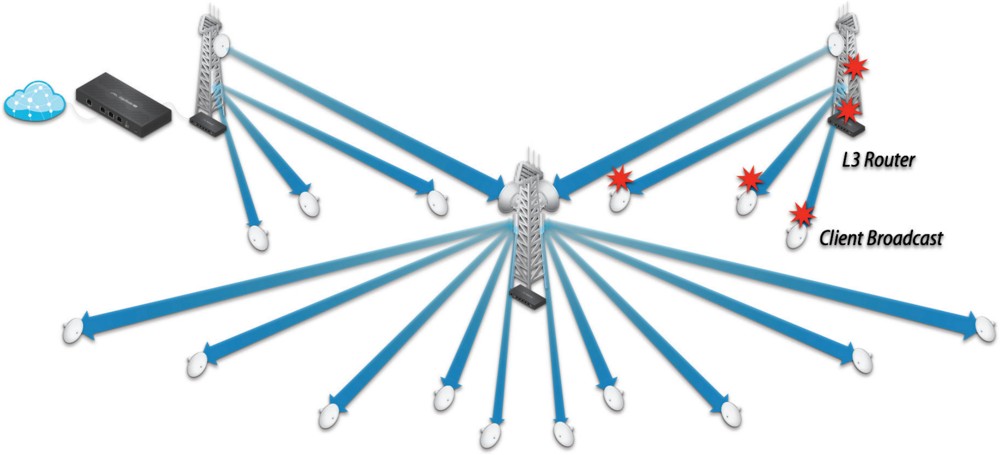


Routed vs. Bridged WISPs

As more subscribers join the network, WISPs face potential problems with scalability at '**layer-2**', or, the local network level. In IPv4 networks, nodes (network devices) frequently use **broadcast messages** to communicate with all nodes on the local network. While necessary for a variety of common protocols, including ARP and DHCP, broadcast traffic has unintended consequences. More nodes means more broadcasts, which drives down the availability of network resources. Eventually, such '**broadcast storms**' cause latency to increase and speeds to decrease to levels that disrupt network activity.



To prevent 'broadcast storms', **routed WISPs** design the outdoor wireless network to limit the size of **broadcast domains**—that is, limit the size of each local, 'layer-2' network segment. Since broadcasts do not pass beyond the 'layer-2' boundary, **routed WISPs** deploy 'layer-3' devices like routers at towers or customer sites. This useful practice requires very basic knowledge of routing, but effectively immunizes the network from 'broadcast storms.' Routed WISPs typically use 'layer-2' switches and radios throughout the network, consciously aware of the size of each local segment.

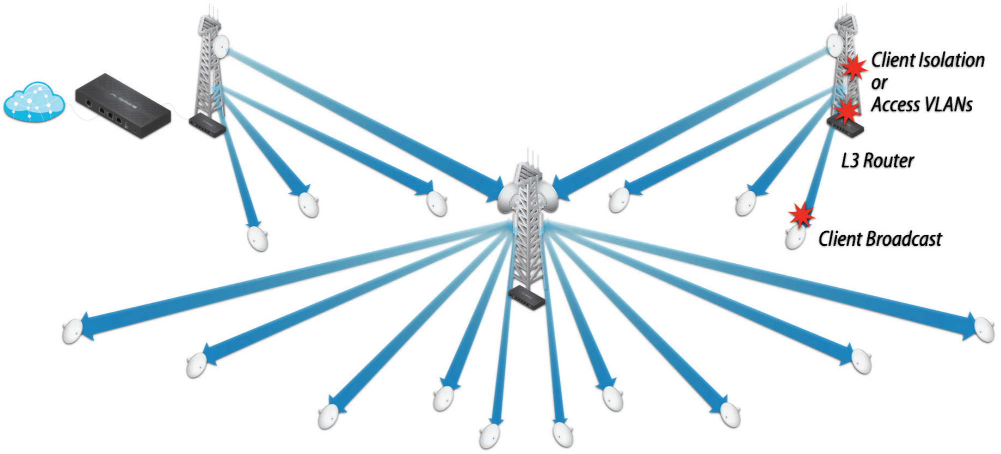


While in **Bridge Mode**, Ubiquiti radios forward all traffic, including broadcasts. While common to radios in PTP links, bridge mode is also recommended on APs in PTMP scenarios to maximize wireless performance.

Router Mode is also supported on airMAX radios, making it useful in Customer Premise Equipment (CPE) scenarios since:

- Separates Customer/WISP Networks
- Limits Broadcast Domain
- Supports NAT & Port Forwarding

Bridged Mode on airMAX radios in CPE scenarios is also practical when integrating airGateway (in Router Mode) in the CPE design. Virtual LANs are a 'layer-2' concept that, when paired with Ubiquiti radios, can enhance the design and security of the WISP network. To learn more about 'layer-2' and 'layer-3' networking topics such as routing and VLANs, consider participating in a Ubiquiti Broadband Routing & Switching (UBRS) course.



Security

Securing the WISP network from unauthorized and malicious users is of paramount importance. Consider the following ways to secure your Ubiquiti radio network:

1. Always run the **latest firmware** listed on Ubiquiti's website, under the downloads section.
2. Change the **default username** and **password** from **ubnt**/**ubnt**. Devices running on public (Internet) and private networks alike are often targeted and exploited if default credentials are used. Rotate passwords regularly.
3. Use **WPA2-AES** for wireless security. Devices with open security can be hacked, despite using non-default credentials. WPA2-AES offers robust encryption at the hardware level, so there is no impact to performance.
4. Keep **config files** secure, as they contain sensitive information like SSID and security keys.
5. Change the **default ports** for **HTTPS** and **SSH** management access.
6. Enable the **Management** (MGMT) **VLAN**. Disable the MGMT VLAN on customer-facing interfaces to lock out unauthorized users.
7. Enable **Client Isolation** at the AP to prevent traffic passing between stations locally, or consider applying **Access VLANs** to radios if customers need to send traffic locally between stations.

Traffic Shaping

Traffic Shaping, or **rate-limiting** is an essential aspect to managing the service provider network. Besides its commercial relevance with **Internet Bandwidth Plans**, traffic shaping is extremely important in maintaining high network performance. Often customers may unsuspectingly connect devices to their network with **viruses** and **other malware**, which could lead to high volumes of public (and private) network traffic. Other customers may unfairly consume network resources through **P2P** and **media streaming** applications. Although traffic shaping does not altogether prevent these issues (as would a router firewall), rate limiting helps reduce the impact that high activity users have on the WISP network.

Traffic shaping is also very important from the perspective of the service provider business. ISPs commonly '**oversubscribe**' or oversell individual Internet data plans beyond what is physically possible for the aggregate rates of the provider network. The **traffic burst** setting allows customers to pass a certain amount of traffic without rate limits during a period. This is particularly useful as customers run Internet speed tests to measure their upstream connection to the Internet. The time duration during which a customer may burst is relative to the burst window (measured in kB), the maximum rate (measured in Kbps), and the rate limit (measured in Kbps), as defined by the following equation:

Burst ÷ Maximum Rate = Time Duration

For example, the maximum rate is 4096 kilobits per second (kbps) and the burst is 2048 kilobytes (kB), or 2 Megabytes. The rate limit is 1024 kilobits per second, applied only after the burst interval is exhausted.

1. Convert burst (kB) to kb: 2048 KB * 8 = 16384 kb
2. Divide traffic burst (in kb) by traffic limit (in kbps)

[16384 kb/(4096 kbp/seconds) = 4 seconds]

Based on these settings, the time duration before the subscriber can burst again without limits is 4 seconds.

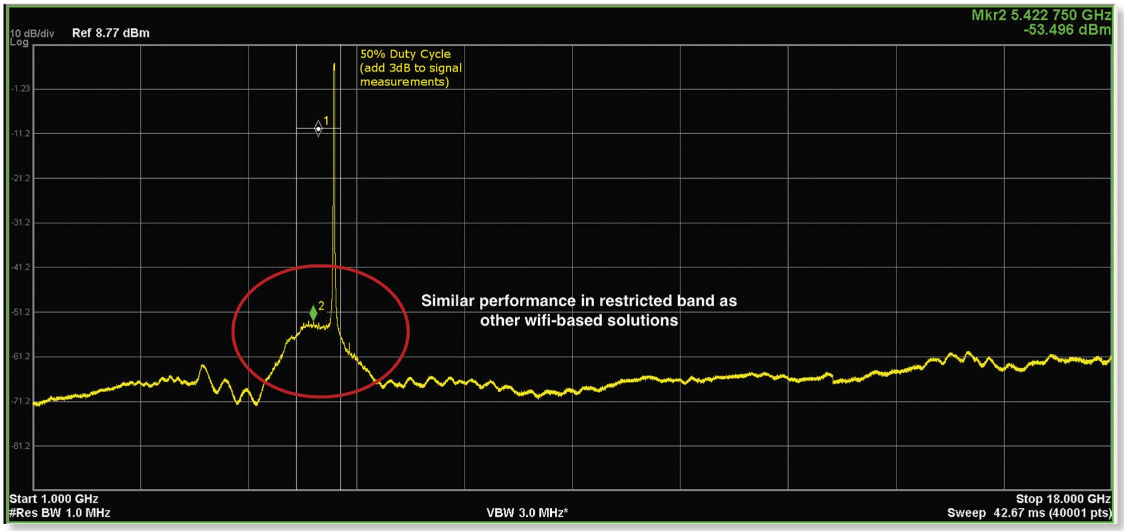
Rate limits are always applied to a **specific interface** (e.g., WLAN0) with respect to a direction. **Egress** refers to traffic exiting an interface, while **ingress** refers to traffic arriving at an interface. Ubiquiti recommends you apply egress rates to an interface, since with ingress rates, an interface cannot control how quickly traffic arrives. If rate limits are configured without the burst specified, then a constant rate limit is applied.

Co-Location

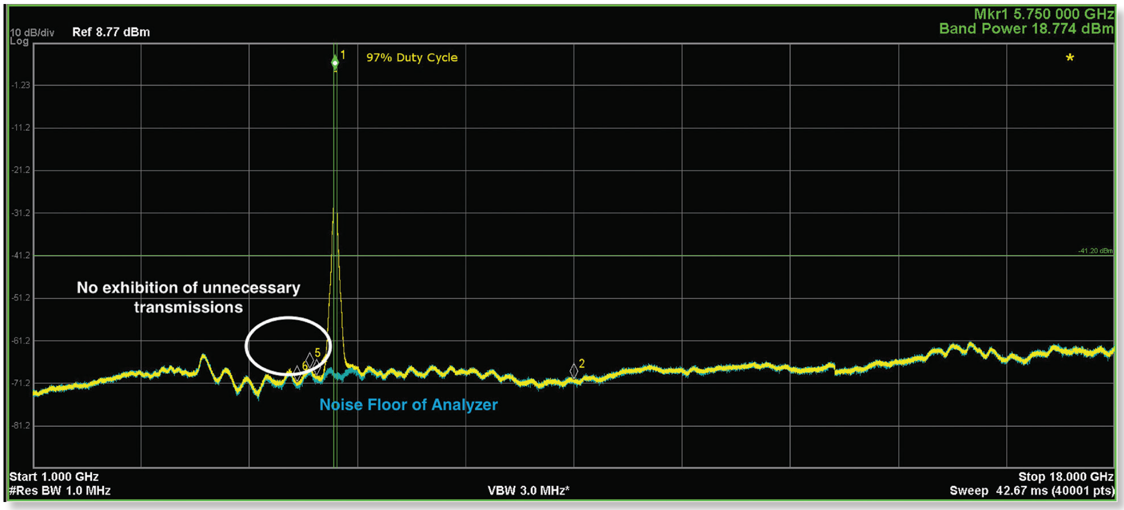
Even with a limited amount of unlicensed spectrum in outdoor wireless networks exists available for WISPs, the problem is further compounded since multiple in-band radios must often be deployed at a common site (e.g., base station tower) to provide complete coverage. **Co-location** describes such scenarios where multiple in-band and out-of-band radios are deployed in close, physical proximity. If this problem is left unaccounted, **co-located radios** can severely hinder the performance of the deployed radios in discussion.

Fortunately, Ubiquiti platforms are designed to overcome the problem of co-location. Consider the following practical and innovative ways to minimize the problem of co-location:

airFiber 'Clean' Spectral Efficiency: airFiber boasts industry-leading Mbps/MHz for maximum possible throughput based on spectrum usage. Compared to the cheap 802.11-based 'Wi-Fi' chipsets responsible for 'polluting' unlicensed bands in many areas today, airFiber uses a proprietary design combined with high-end RF components for unparalleled performance, without compromising spectral integrity. This is evident in the following figures, which compare the transmit masks of a Wi-Fi-based competitor radio (poor output, TX spurs, illegal out-of-band emission) to that of the AF5-X (clean output, sharp tail-ends, legal emission):



Competitor Radio Poor, Illegal Spectral Performance



airFiber5-X 'Clean,' Excellent Spectral Performance

airPrism Active Filtering: airPrism-equipped radios like Rocket-ac PTMP and PTP employ robust, active filters to counter adjacent channel interference, reducing the noise levels by as much 30 dB+. Compared to the transmit mask efficiency of airFiber, airPrism is a **receiver technology** for select airMAX products.

Highly Directive Antennas: Ubiquiti antennas are expertly designed for maximum gain and minimal '**leakage**.' The result is a strong signal at the remote radio without concern for exaggerated noise levels in the immediate vicinity of the transmitter. Pay particular attention to **front-to-back ratio** and **sidelobes** as illustrated by Ubiquiti radiation patterns. Always use the most directive antenna for the application.

Deployment Distance: As the **physical distance** between two or more in-band RF systems increases, the effective level of radiated power each radio 'hears' from the other(s) decreases, due to **path loss**.

IsoBeam & RF Shielding: Ubiquiti airMAX-ac and airFiber equipment feature improved hardware enclosures to reduce the amount of 'RF leakage' during transmission while simultaneously limiting the interference 'heard' by nearby sources of RF energy during reception. Commonly, operators install separate metal shield kits along the back sides of sector antennas to minimize the amount of unwanted energy radiating from and arriving at the RF system. The IsoBeam features additional RF isolation to protect against co-location interference for certain airMAX devices, especially in PTP links.

Channel Reuse Patterns: Assign channels in patterns that appropriately match the radiation patterns for the chosen, co-located antennas. For example, if four 90° sector antennas are co-located to provide 360° of non-overlapping coverage, use an ABAB pattern to maximize channel efficiency with minimal noise levels. Consider also using separate frequency bands for backhaul (e.g., 24 GHz) and PTMP (e.g., 5 GHz).

Channel Bandwidth & Spacing: Assign channel widths based on actual need, rather than choosing the largest width available. This not only boosts the signals, but also decreases noise floors (by 3 dB per halved channel). Also include as much space as possible between channels of neighboring radios to avoid/reduce adjacent channel interference.

Radio GPS Synchronization: Special Ubiquiti radio models support GPS synchronization, allowing transceivers to use pre-determined time intervals for transmitting and receiving. By design, all nearby in-band radios should participate in the same GPS sync. In this way, the co-located radios transmit and receive simultaneously, **without self-interfering**. Because none of the synced, in-band radios are transmitting during receive intervals, the noise floor remains very low. This ensures a high SNR across all current and future synced radios.

Reliability & Redundancy

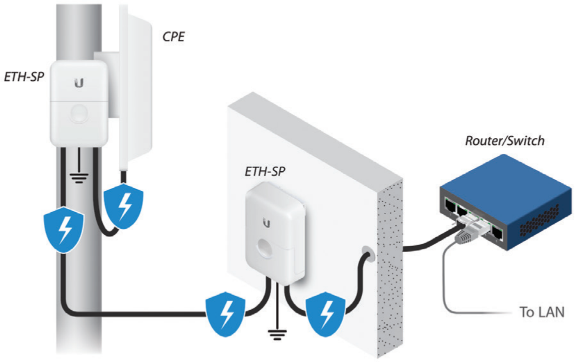
In order to provide the best possible subscriber experience, WISPs are primarily concerned with network performance. Ubiquiti manufactures wireless and wired equipment designed for maximum uptime, low jitter/latency, and high throughput. However, unforeseen events (e.g., poor weather conditions) can cause equipment to operate unexpectedly.

Deploying **redundant radio links** for backhaul is particularly important, as a single point of failure with backhaul could lead to complete subscriber outage across multiple locations downstream. For example, two AF5 links on the same local network segment could be configured with **Spanning Tree Protocol** so when one link stops passing traffic, the other link is used. Ubiquiti's EdgeMAX platform also provides solutions for redundancy and **load-balancing** at both 'layer-2' and 'layer-3.'

Grounding

While Ubiquiti equipment is designed and manufactured for durability/longevity in all climate types, you are also responsible for protecting your gear against **electrostatic discharge** (ESD) and other electrical events that may reach and damage the sensitive electronic components. ESD occurs as electrical charges build up and travel through conductive materials, such as cables and wires. Consider the following tips when designing a properly grounded installation site:

1. **Use Shielded Cables**: Ubiquiti's TOUGHCable **Shielded Twisted-Pair** (STP) Ethernet cables have a **drain wire** to ground the cable. They also feature a **weatherproof jacket** and **cable shielding** against EMI sources.
2. **Ground All Equipment**: Make sure that all equipment at the installation site is properly grounded, including switches, routers, and radios. Even a single point of entry for an electrical charge could lead to multiple incidents of damage.
3. **Install Surge Protection**: Ubiquiti **Surge Protectors** (ETH-SP) should be installed throughout the grounding circuit to add electrical buffers between equipment.
4. **Check Datasheets**: Most Ubiquiti equipment features design/hardware enhancements to increase ESD protection, such as shielded Ethernet ports or grounding rings.



5. **Examine Site**: Not all regions feature AC outlets with grounding, which further increases your responsibility to adequately ground the equipment. Be conscious of nearby metal surfaces and mount RF equipment well below the highest point of the installation structure to reduce the risk of a lightning strike.

A. Glossary

- **802.11 Wireless** Industry standard for data communication based on CSMA/CA, typically operating in UHF to SHF (300 MHz - 30 GHz). airMAX combines this physical-layer technology with proprietary TDMA mechanisms.
- **ACK Frame** In TDD/TDM systems, these frames are sent to confirm receipt of data frames. Inherently, this adds overhead and latency.
- **airMAX Protocol** Ubiquiti's proprietary, TDMA protocol for outdoor wireless networks that features intelligent station polling, built-in packet prioritization (QoS), and support for the latest 802.11 standard.
- **airPrism** An active radio frequency filter built into Ubiquiti's custom silicon that improves performance in noisy environments.
- **Airtime** The average wireless bandwidth usage as a percentage of the maximum theoretical bandwidth utilization, expressed as a percentage, where aggregate airtime is shared among all stations.
- **Airtime Efficiency** Measures a radio's tendency to maximize use of its time slots when sending and receiving data (where 100% = highest data rates, lowest retries).
- **airView** A free, built-in tool available on all airMAX devices that scans and collects frames in the RF environment, displaying their energy signatures in real-time; airMAX-ac devices can run airView without dropping wireless connections.
- **Antenna Reciprocity** Gain has a positive, bidirectional effect on the receive signals at both ends of a wireless link.
- **Asymmetric DSL (ADSL)** DSL broadband that yields higher bandwidth downstream than upstream.
- **Attenuation** The rate at which signal intensity decreases, whether by obstructions or path loss.
- **Backhaul** A high-throughput, robust link that typically extends a long distance in order to serve a remote location.
- **Bandwidth** See *Channel Width*.
- **Base Station** An AP in a PtMP network that uses a semi-directive antenna for wider coverage (45-360°) to connect multiple clients/subscribers.

- **Bridge Mode** The wired and wireless interfaces are linked under a single, bridge interface to extending broadcasts through the wireless link.
- **Beamwidth** The main lobe's angle of coverage measured -6 dB back with Ubiquiti antennas.
- **Cable** Broadband access method that typically uses co-axial lines, but bandwidth is shared among subscriber CPEs in an area.
- **Capacity** The approximate data rates of a wireless link that also considers overhead from the 802.11 wireless protocol.
- **Carrier-Sense Multiple Access, Collision Avoidance (CSMA/CA)** Whenever a wireless station needs to use the channel, it listens prior to transmitting.
- **Carrier Signal** The modulated signal containing the data.
- **Chain** A radio transceiver (transmitter and receiver).
- **Channel Flexing** The process by which the channel width is adjusted to meet the needs of the wireless link. Increased channel width means increased throughput potential, while decreased channel width means increased power density (greater signal strength).
- **Channel Width** Also known as bandwidth, represents the range of frequencies used by the radio (e.g., 10 MHz, 20MHz, 40 MHz). Although wider bandwidths allow for higher data rates, smaller bandwidths are better-suited for long-distance PtP links.
- **Country Code** The available frequencies/channels for the radio based on regional laws.
- **Cross-Polarization Discrimination (XPD)** The ability of the antenna to isolate signals across separate polarities, since the elements of an antenna are never totally polarized in a given plane.
- **Customer Premise Equipment (CPE)** The devices installed at the edge of the network that connect to the AP Base Station; typically use a highly-directive antennas.
- **Decibels (dB)** A logarithmic ratio, useful for expressing very large or very small values. Decibels over Isotropic Radiator (dBi) measures antenna gain; decibels over milliwatt (dBm) measures power levels.
- **Digital Subscriber Line (DSL)** Physical layer service (twisted-copper pairs) for last mile telephony and Internet. Each CPE modem talks back to one or more DSLAMs (DSL Access Multiplexers) located at provider CO (central office).
- **Effective Isotropic Radiated Power (EIRP)** The total amount of power radiated toward the receiver, taking into consideration transmit power, antenna gain, and any losses (e.g. cables, connectors).

- **Electrical Downtilt** A property common to sector and omni antennas visible in the elevation polar plots that introduces a slight downward angle at which energy radiates.
- **Electrostatic Discharge (ESD)** Undesired electrical currents that may reach and damage the sensitive electronic components of service provider equipment.
- **Electromagnetic Interference (EMI)** Radiation from the electromagnetic spectrum that contributes to the overall noise floor (e.g., microwave ovens, cordless telephones).
- **Error Vector Magnitude (EVM)** The deviation measurement of a symbol from its perfect representation; as modulation becomes more complex, there is less room for error — clean radio performance is synonymous with good EVM and results in higher speeds.
- **Fade Margin** A signal buffer used when planning link power budgets that helps account for a dynamic RF environment (e.g., rain fade). Ubiquiti recommends 15+ dB of fade margin for WISP networks.
- **Filters** Designed to allow signals belonging to a particular band/frequency pass through, rejecting signals outside this range.
- **Free Space Path Loss (FSPL)** The tendency of a signal to expand outward as it propagates through space, causing the signal to attenuate.
- **Frequency** The number of periodic cycles an electromagnetic waves traverses per second, measured in Hertz (Hz); compared to higher frequencies, lower frequencies propagate farther (e.g., 2.4 GHz propagates better than 5 GHz). Also synonymous with channels, the center frequency on which the radio signal is generated.
- **Frequency Division Duplex (FDD)** A full-duplex protocol that uses separate frequencies for separate data streams.
- **Fresnel Zones** Ellipsoid-shaped areas that represent the true line-of-sight between two radios.
- **Full-Duplex** The default method for 802.3 Ethernet communication; an Ethernet interface can transmit and receive simultaneously; airFiber supports full-duplex communication for high-throughput links at shorter distances.
- **Gain** A measurement in dBi of an antenna’s ability to focus the radiated energy (from the radio) into a particular coverage area. Higher gain means greater directivity, propagating the signal farther.
- **Harmonics** Inherent TX spurs occurring at multiples of the radio clock (e.g., an airMAX M900 radio set to operate on 907 MHz center frequency will emit clock spurs on 1814, 2721, 3628, 4535, and 5442 MHz).

- **Half-Duplex** The default method for 802.11 wireless communication; the radio either transmits or receives, but never both simultaneously.

- **Hidden Node** Outdoor wireless CSMA/CA stations with a common AP Base Station that are unable to 'hear' each other when transmitting simultaneously, causing a receive collision at the AP.

- **Hybrid-Division Duplexing (HDD)** A patented Ubiquiti technology that improves the efficiency of the traditional TDD protocol.

- **In-Band** Signals/noise from radios in the same frequency band (e.g., 2.4 GHz radios on channels 1-13 from the perspective of a 2.4 GHz radio).

- **Internet Exchange Point (IXP)** A common location where ISPs can publicly interconnect, usually a large data center.

- **Interference** Represents the average energy level derived from sources of EMI sources, principally competing radio networks.

- **Isotropic Radiator** A theoretical antenna system that radiates in all directions equally, without loss.

- **Last Mile** Refers to the ISP's edge infrastructure reaching the customer.

- **Line-of-Sight** The elliptical zone (not simply a straight line) that must be remain unobstructed (e.g., trees, buildings) for optimal wireless performance.

- **Link Power Budget** An estimation tool used to calculate receive signal relative to wireless link variables including distance, transmit power, and antenna gain.

- **Multiple-In, Multiple-Out (MIMO)** The use of multiple radio chains and antennas for signal diversity and increased spatial streams.

- **Modulation** Discrete changes in frequency, amplitude, and phase in order to represent information bits.

- **Noise Floor** The average energy level derived from local noise sources, including receiver radio operation and thermal noise (dependent on channel width).

- **Non-Overlapping Channels** Channels whose bandwidth edges do not overlap.

- **Orthogonal Frequency-Division Multiplexing (OFDM)** Individually modulated sub-carriers represent data across the channel width.

- **Output Power** The level of power generated by a transmitter radio before passing through transmission lines and antennas.

- **Out-of-Band** Signals/noise from radios in a different frequency band (e.g., 5 GHz channels from the perspective of a 24 GHz radio).
- **Path Loss** See *Free Space Path Loss (FSPL).*
- **Peering** The interconnection of ISPs to move traffic across networks, such as the Internet.
- **Polar Plot** See *Radiation Pattern*.
- **Polarity** The plane along which an electromagnetic wave travels through space.
- **Point-of-Presence** Represents the demarcation point where an ISP's network ends.
- **Point-to-Point (PtP)** A wireless link featuring an AP and Station typically with highly directive antennas in backhaul scenarios.
- **Point-to-Point-Protocol over Ethernet (PPPoE)** A popular, layer-2 transport mechanism for establishing and authenticating subscribers in service provider networks in Ethernet frames.
- **Point-to-MultiPoint (PtMP)** An AP Base Station connects to multiple clients across a wide coverage area (45-360°).
- **Power Spectral Density (PSD)** The amount of energy relative to the transmitted signal across the entire channel bandwidth.
- **Radiation Pattern** A graphical depiction of the antenna gain at different angles on a given plane.
- **Radome** A radome is an enclosure designed to protect an antenna from weather and damage while still allowing electromagnetic radiation to pass through.
- **Rain Fade** Signal attenuation due to precipitation; as frequency increases, rain fade also increases.
- **Receive Signal** Also known as RX Signal / Signal Strength, this represents the average combined energy level arriving at the receiver radio.
- **Receiver Antenna (RX Antenna)** The device that filters unwanted signals and converts the transmitter's weakened radio waves back to an electrical signal.
- **Receiver Radio (RX Radio)** The device that amplifies and converts the signal back to its original waveform for information data to be retrieved.
- **Return Loss** See *Voltage Standing Wave Ratio*.

- **Router Mode** Segments the wireless (WAN) and wired (LAN) interfaces, stopping broadcasts on both sides of the link.

- **Rule of 3's and 10's** Each time you add/subtract 3 dB, you must multiply/divide the linear value by a factor of 2. And each time you add 10 dB, you must multiply/divide the linear value by a factor of 10.

- **Satellite** Satellite receivers are ideal for remote Internet access, where no other option exists; works in SHF (Super High Frequency) range 3-30 GHz.

- **Security** The wireless protocol and encryption method used to secure a wireless radio link.

- **Selectivity** The ability of the receiver to 'listen' to the desired signal while blocking out other in-band channel sources.

- **Sensitivity** The ability of the receiver to 'listen' to weakened signals. The greater the sensitivity of the radio, the weaker the signals it can receive.

- **Service Set Identifier (SSID)** The beacon frame containing information about the AP wireless network, announced in regular intervals.

- **Shannon-Hartley's Theorem** The maximum data capacity of an information channel is dependent on SNR and channel width.

- **Signal-to-Noise Ratio (SNR)** The difference in the average receive signal (e.g., -50 dBm) and average noise levels (e.g., -59 dBm); SNR is measured in dB (e.g., 9 dB).

- **Signal Strength** See *Receive Signal*.

- **Site Survey** A tool that collects information contained in SSID announcements about neighboring wireless networks in the vicinity of an airMAX radio.

- **Spanning Tree Protocol (STP)** A layer-2 network protocol used with redundancy to prevent bridge loops.

- **Spatial Filtering** The ability of an antenna to 'focus' in a particular direction, improving the SNR not only for the local receiver but for other nearby, in-band receivers.

- **Station** May refer to the radio connecting to an Access Point or generally refer to any wireless radio.

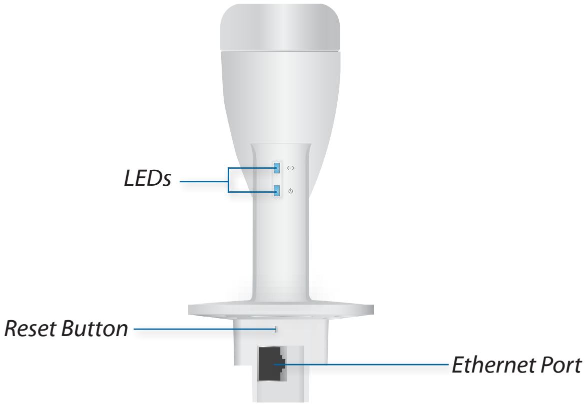
- **Symbol Sets** Groups of modulated bits appearing on the constellation diagram of a radio.

- **Thermal Noise** An inherent property related to the size of the wireless channel. The greater the channel width, the higher the thermal noise level.

- **Tier 1 ISP** A large, global provider, whose networks form the backbone of the Internet.
- **Tier 3 ISP** A smaller, regional provider, that reaches the end-user through Last-Mile networks.
- **Time Division Multiple Access (TDMA)** A channel access method by which the common AP divides the wireless channel into time slots for each connected station, which avoids receive collisions.
- **Time Division Duplex (TDD)** A half-duplex protocol designed to split the time domain among wireless stations.
- **Throughput** The true amount of data passing through a wireless link based on TCP/UDP measurements; throughput is typically just over half of the wireless capacity.
- **Traffic Shaping** Rate limits and windows of bandwidth applied to CPEs.
- **Transmission Line** The connections between the radio and antenna over which an electrical signal can pass.
- **Transmitter Antenna (TX Antenna)** The device that converts the received signal into radio waves, which are propagated into a given direction based on the type of antenna.
- **Transmitter Radio (TX Radio)** The device that converts information data (0's and 1's) to an electrical signal in the form of a carrier waveform.
- **TX Spurs** Random, undesired transmissions along the frequency band of the carrier radio outside the channel width.
- **Voltage Standing Wave Ratio (VSWR)** Measures the amount of energy that is reflected back and wasted on a transmission line (e.g., antenna feed, RP-SMA connectors) connecting the radio chain and antenna.
- **Weakest link** Because airtime is shared among stations in a PtMP network, a single poor quality client can reduce the entire aggregate performance.
- **Wide Area Network (WAN)** Represents the upstream network, past the boundary of the LAN.
- **Wireless** Includes the 802.11 standard, typically operating in UHF to SHF (300 MHz - 30 GHz).

B. Appendices

airMAX Device Reset Method



Antenna Feed

Method #1 (Recommended)

All airMAX devices feature a “Reset to Factory Defaults” button on the chassis. After the airMAX device has been powered on for 60+ seconds, press and hold the reset button for 10+ seconds. After the Power/Link LEDs flash, the airMAX device will reboot and, after 60+ seconds, return to its default IP address of 192.168.1.20.

Method #2

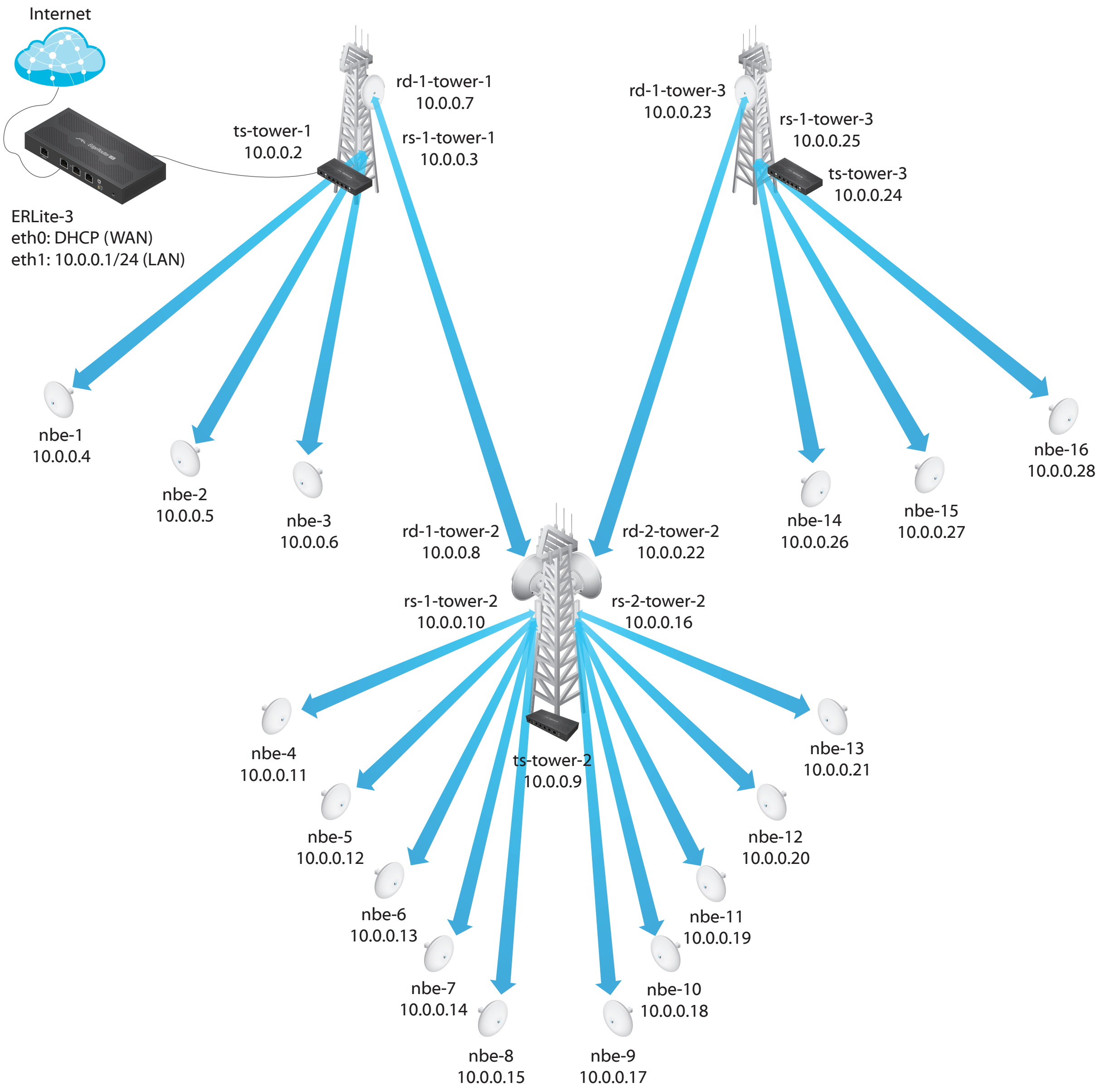
Certain POE adapter models feature a built-in reset button to remotely reset the airMAX device. Make sure, however, that the connected airMAX device supports the electrical output range of the POE adapter.

Method #3 (Not Recommended)

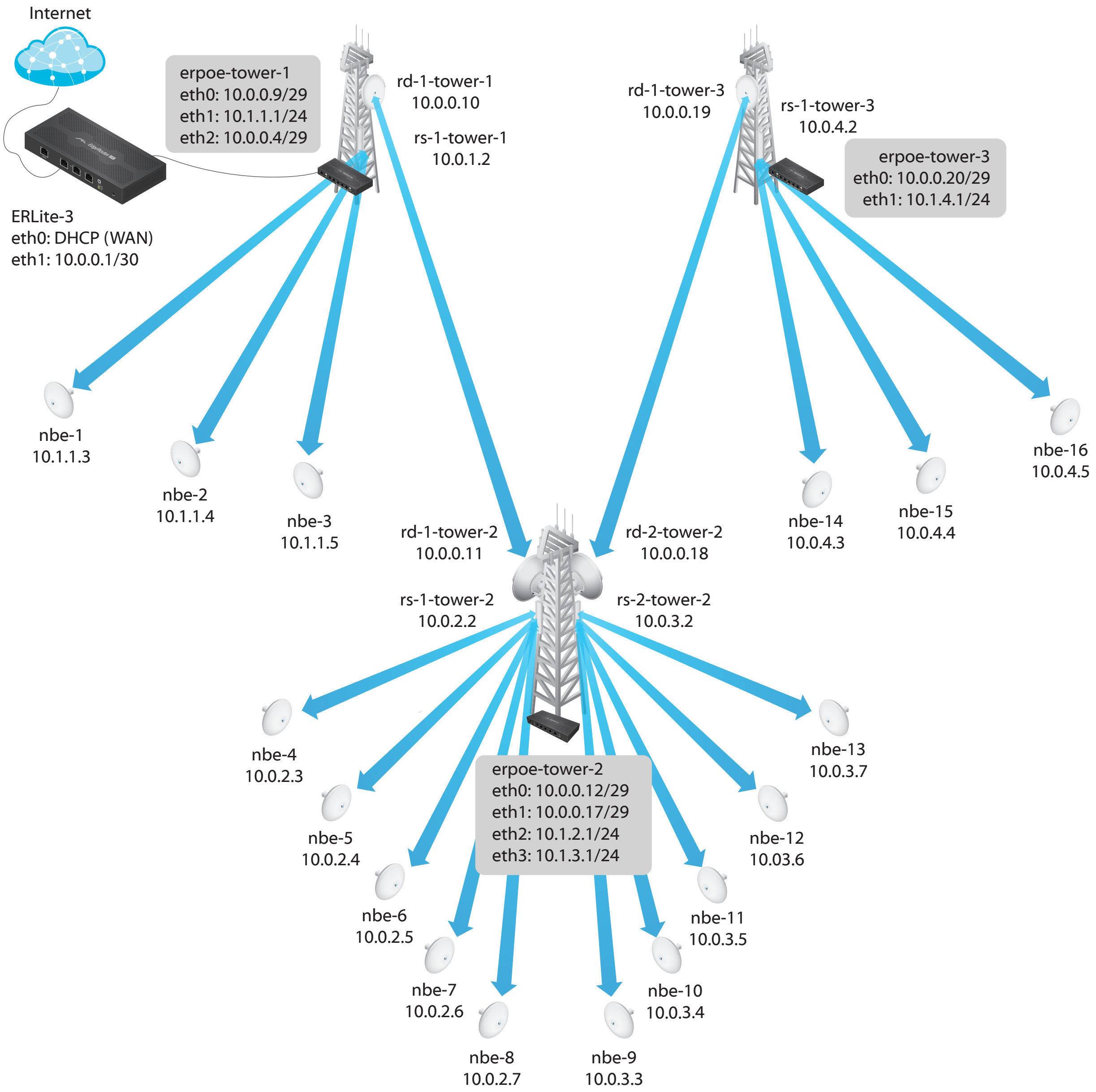
The TFTP reset method is a last-resort method used to recover a ‘bricked’ device that does not respond on its default IP address. Only use this method if the device cannot be recovered via the aforementioned reset methods. This is only mentioned for advanced users and should not be attempted during the Ubiquiti training course. In order for the airMAX device to enter TFTP recovery mode, press and hold the reset button (while the POE cable is disconnected). Keep the reset button depressed as you reconnect the POE cable to the airMAX device. After 10+ seconds, the device LEDs will begin to flash in an alternating pattern, indicating that the airMAX device is now in TFTP recovery mode, responding to pings on the default address, 192.168.1.20. Using a TFTP client, upload the firmware to the airMAX device to restore the device to factory default settings.

Sample Topologies

Layer-2 Bridged WISP



Layer-3 Routed WISP



Reference Charts

Path Loss

Distance (km)	2.4 GHz	5.8 GHz
0.5	94	102
1	100	108
1.5	104	111
2	106	114
2.5	108	116
5	114	121
7.5	118	125
10	120	128
15	124	131
20	126	134
25	128	136
30	130	137
40	132	140
60	136	143
80	138	146

airMAX Default QoS and WME Values

802.1p Class of Service	ToS Range	DSCP Range	WMM Category
0-Best Effort	0x00-0x1f	0-7	Best Effort
1-Background	0x20-0x3f	8-15	Background
2-Spare	0x40-0x5f	16-23	Background
3-Excellent Effort	0x60-0x7f	24-25, 28-31	Best Effort
4-Controlled Load	0x80-0x9f	32-39	Video
5-Video (<100ms latency)	0xa0-0xbf	40-45	Video
6-Voice (<10ms latency)	0x68, 0xb8, 0xc0-0xdf	26-27, 46-47, 48-55	Voice
7-Network Control	0xe0-oxff	56-63	Voice

Modulation and Data Rates

HT MCS Index	Spatial Streams	Modulation & Coding	Data Rate GI=800ns	Data Rate SGI=400ns	Data Rate GI=800ns	Data Rate SGI=400ns	Data Rate GI=800ns	Data Rate SGI=400ns	Data Rate GI=800ns	Data Rate SGI=400ns	VHT MCS Index
			20MHz		40MHz		80MHz		160MHz		
0	1	BPSK 1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	65	0
1	1	QPSK 1/2	13	14.4	27	30	58.5	65	117	130	1
2	1	QPSK 3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195	2
3	1	16-QAM 1/2	26	28.9	54	60	117	130	234	260	3
4	1	16-QAM 3/4	39	43.3	81	90	175.5	195	351	390	4
5	1	64-QAM 2/3	52	57.8	108	120	234	260	468	520	5
6	1	64-QAM 3/4	58.5	65	121.5	135	263.3	292.5	526.5	585	6
7	1	64-QAM 5/6	65	72.2	135	150	292.5	325	585	650	7
	1	256-QAM 3/4	78	86.7	162	180	351	390	702	780	8
	1	256-QAM 5/6	n/a	n/a	180	200	390	433.3	780	866.7	9
8	2	BPSK 1/2	13	14.4	27	30	58.5	65	117	130	0
9	2	QPSK 1/2	26	28.9	54	60	117	130	234	260	1
10	2	QPSK 3/4	39	43.3	81	90	175.5	195	351	390	2
11	2	16-QAM 1/2	52	57.8	108	120	234	260	468	520	3
12	2	16-QAM 3/4	78	86.7	162	180	351	390	702	780	4
13	2	64-QAM 2/3	104	115.6	216	240	468	520	936	1040	5
14	2	64-QAM 3/4	117	130.3	243	270	526.5	585	1053	1170	6
15	2	64-QAM 5/6	130	144.4	270	300	585	650	1170	1300	7
	2	256-QAM 3/4	156	173.3	324	360	702	780	1404	1560	8
	2	256-QAM 5/6	n/a	n/a	360	400	780	866.7	1560	1733.3	9

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We'd like to hear your feedback!
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