Radios, Antennas and Other Wi-Fi Essentials

Ruckus Wireless | White Paper

The Importance of RF Signal Control on Wi-Fi Stability and Performance

Doesn't Everyone Already Understand Wi-Fi?

Wi-Fi (802.11) is an access technology that connects IP devices to a wired network using wireless radios. The client devices have radios (wireless adapters) that connect to access point (AP) radios. These radios transmit over unlicensed radio spectrum; either the 2.4 GHz or 5 GHz bands.

So how does an IT manager determine the best Wi-Fi solution for their network? While most IT engineers are very familiar with IP networking, they aren't always experts in radio technology - a different beast altogether. Until the commercialization of Wi-Fi, most IP networks did not utilize radio-based technology. Now radios are crammed into virtually every type of device imaginable.

So the inevitable choice arrives — which product is better? There are a lot of features different vendors will tout, but ultimately Wi-Fi performance and reliability, the top two requirements of any wireless networks, comes down to two essentials:

- **IP networking** — a Layer 2/3 networking technology
- **Wi-Fi radio and antenna** — a Layer 1 access medium

When asked which one affects Wi-Fi performance the most, it will always be the Wi-Fi radio, antennas and related technology. Before performance metrics like TCP throughput can be discussed, the radio signal must be transmitted and received.

Are All Radios the Same?

Radios everywhere but there are relatively few radio chipset vendors on the market today; these include manufacturers such as Intel, Broadcom, Atheros, and Marvell. Most Wi-Fi equipment vendors use the same radio chipsets and have access to all the same capabilities. So where is the difference? Where's the value-add that sets one AP apart from the pack?

Generally speaking, the same chipset tends to provide the same performance for any vendor if all else is equal. Yet different implementations by each vendor can yield very different performance results. There is one more piece to the RF story: better antennas.

The antenna is where radio waves hit the air for the very first time. The antenna shapes those waves and transmits them - setting the stage for RF performance. Different antennas connected to the same radio can have very different performance numbers.

Once an RF signal has left the AP's antenna there is nothing else that radio can do to make it better (or worse). Once a signal has been sent, it either reaches the client within a certain period of time — or it doesn't. Clearly Wi-Fi performance is heavily dependent on radio antenna performance. Up until the radio, it's pure IP networking – but after the radio, it's all about how signals are sent and received that most determine the stability and performance of a Wi-Fi network.

A Primer on Antennas

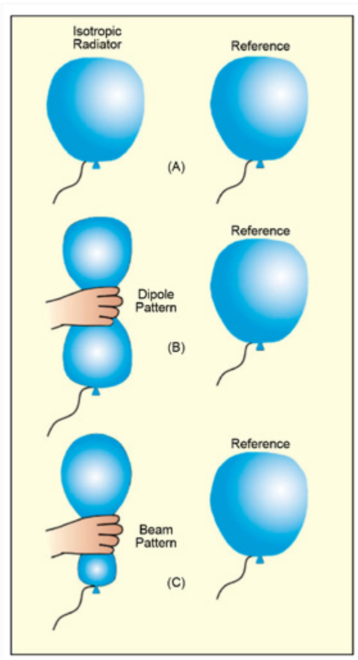
An antenna provides three things to a radio: gain, direction and polarization.

Gain is the amount of increase in energy that an antenna adds to the RF signal. Direction refers to the shape of the transmission, which describes the coverage area. Polarization is the orientation of the electric field (transmission) from the antenna.

These three characteristics can create huge differences in performance between one antenna and another — even when connected to the exact same radio.

Signal Gain

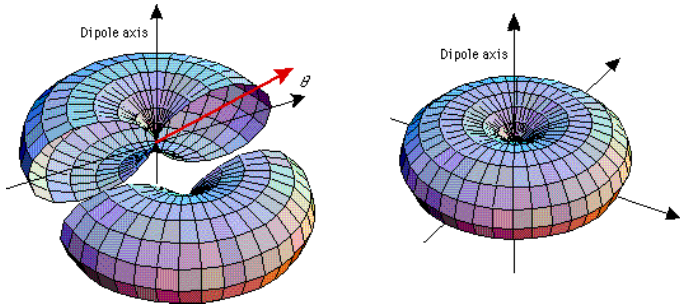
Gain is a measurement of the degree of direction within an antenna's radiation pattern. An antenna with a low signal gain transmits with about the same power in all directions.



Conversely, a high-gain antenna typically transmits in a particular direction. Signal gain focuses the RF emission and improve signal quality, but it doesn't add power. Think of it like a balloon — at rest the air inside fills out the balloon fairly uniformly. Squeezing one end of the balloon however, results in the other side getting larger as the air is forced to one side. But no matter what pressure is applied, there will always be the same amount of air inside.

Better yet, imagine pressing down on the balloon — you'll end up with a doughnut shape (toroid). This is essentially what an omnidirectional antenna's RF field looks like. *(Figure 1)*

FIGURE 1: 3D Omnidirectional Antenna Pattern



It's important to remember that antennas cannot add power to wireless signal but can focus the RF energy. The amount of energy will always stay the same, but signal gain can help achieve longer distances as well as higher signal quality. From this information it's inferred that the higher the signal gain, the narrower the beamwidth. This is because energy is being focused (like squeezing the balloon). That means taking energy from some other direction to focus somewhere else - which is one reason why very high-gain antennas are typically not omnidirectional.

Most omnidirectional antennas have some gain, but it's usually low — around 2-3 dBi. This makes sense when you think about it; that doughnut shape discussed earlier is biased towards a more horizontal shape. A more horizontal signal transmission is usually better for clients since they are usually oriented towards an AP horizontally, rather than vertically.

As the signal gain on an omnidirectional antenna goes up, the doughnut shape will become flatter and flatter. This squeezes the signal out further and further on a horizontal plane at the expense of the vertical *(See Figure 2, next page)*.

Direction

As discussed previously, an antenna has a certain amount of RF energy and this energy an be focused through signal gain. But signal gain also tends to give directionality to an RF signal (i.e., it sends more (most) energy in one direction rather than another). Even omnidirectional antennas have some small amount of signal gain that is one of the reasons[1] they are not a perfect spherical shape.

Directional antennas are used when signal is desired in a certain or specific direction. A wireless bridge is a good example

1 An antenna that could transmit a perfect sphere of energy is called an *isotropic radiator*. This is a theoretically ideal antenna shape and not something that can be manufactured. When an antenna's signal gain references a lossless isotropic antenna, the gain is expressed in dBi. When the reference is a half wave dipole antenna, the antenna gain is expressed in dBd (0 dBd = 2.15 dBi).

FIGURE 2: Longest and Shortest Signals for an Omnidirectional Antenna

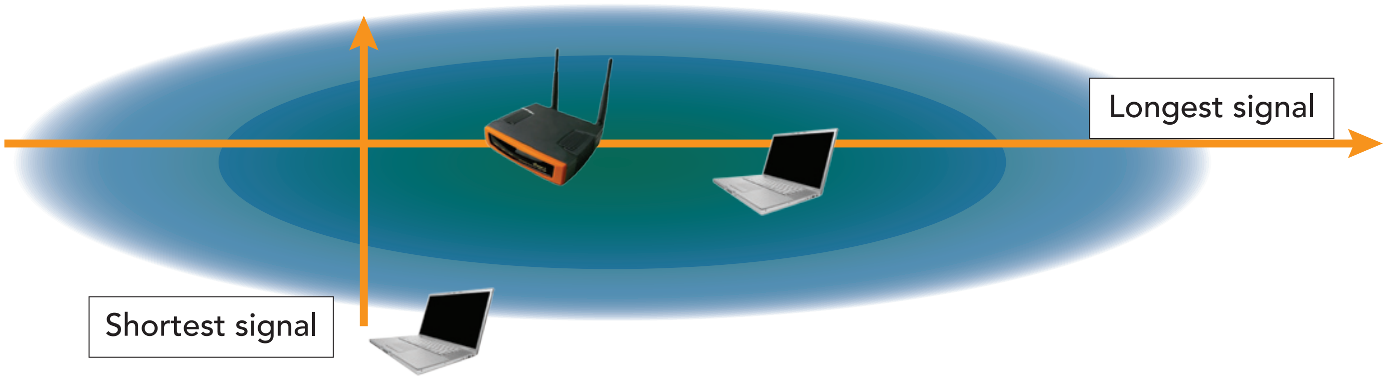
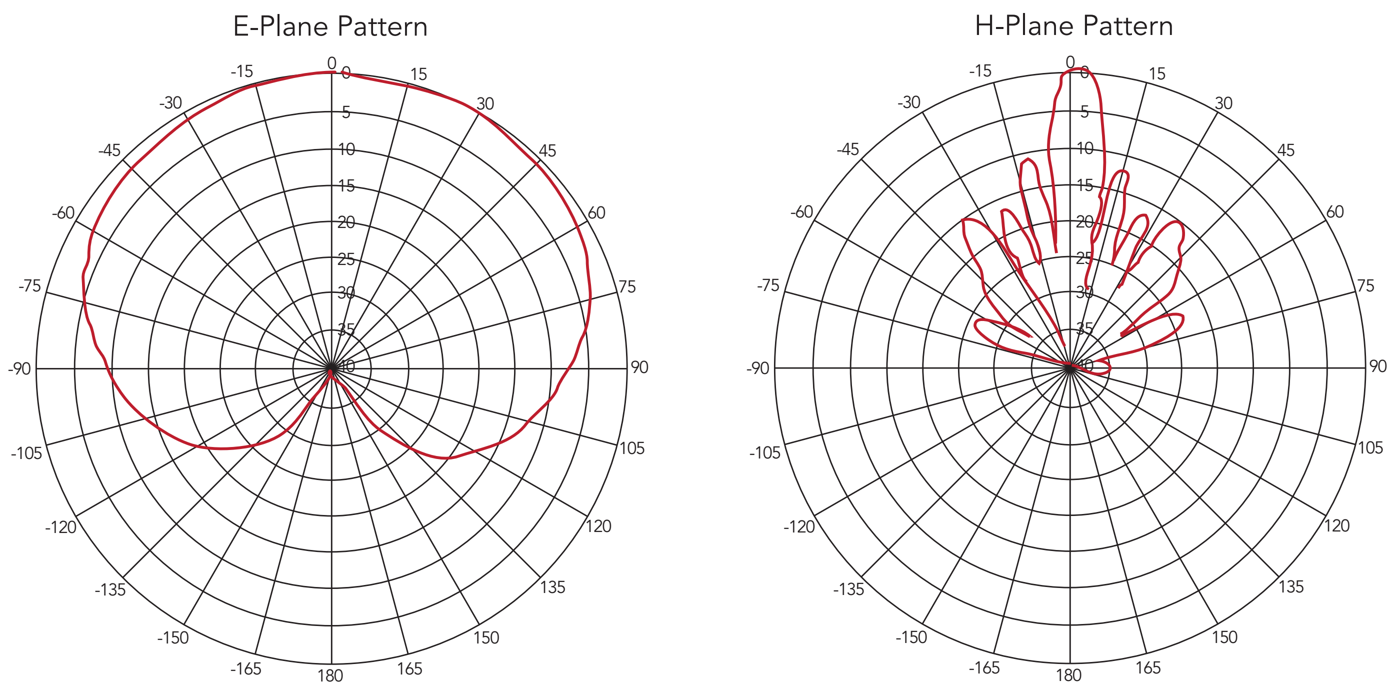


FIGURE 3: Directional Antenna Polar Plot



of when to use a directional antenna because the receiving end of the bridge if effectively fixed and won't move. So rather than waste precious RF energy transmitting to where the bridge is not located, push all of it in the right direction instead.

Consequently, the antenna will have a high signal gain as it focuses the signal and shapes it in a particular direction. Of course RF is not a transmitted in a perfectly straight line. Directionality doesn't mean that the signal is focused like a laser beam, but more like a cone. The energy will naturally spread out over distance. Directional antennas are measured in terms of beamwidth, for example 10°, 60°, 90°, 120° and so on.

Figure 3 shows the antenna pattern for a 17 dBi linearly polarized directional antenna. This is a very common way of illustrating the shape of an antenna. The left-hand picture is the E-Plane, which shows the plane of the electric field generated by the antenna.[2] The red line shows the shape, which is highly directional and transmits entirely in one direction with very little transmission in any other direction. The H-Plane shows the largest shape – called the primary beam — the next largest shapes on either side are called side lobes.

2 The H-Plane lies at a 90° angle to the E-Plane. This is also called the azimuth plane.

The right-hand diagram (*Figure 3*), the H-Plane, is a slice through the beam at 90° from the other picture. It shows the beamwidth, which is 60°. How did we get 60°? It's fairly simple. Remember, RF signals lose half their power with every 3 dB loss in gain or power.

The width of a beam is measured at the point of half-power, or 3 dB. Each circle in the plot represents 5 dB and the numbers on the outside of the circle correspond to a compass. If you look for the point where the red figure is about half-way between the outermost black circle (0 dB) and the first circle inside (5 dBm), you'll have the 3 dB beamwidth, or 60°.

Polarization

Polarization is the orientation of the signal as it leaves the antenna. All antennas have some kind of polarization. There are many different kinds of polarization, however most Wi-Fi antennas are linearly polarized and will have either vertical or horizontal polarization. *(See Figure 4)*

Polarization is important because it describes the orientation in which most signals will be transmitted. Any Wi-Fi device must have an antenna, and that antenna has a polarization. Many Wi-Fi clients use vertically polarized antennas.

APs equipped with "rubbery ducky" style antennas are usually polarized in one direction. It's important to understand how they are polarized so the antennas can be flipped into the right position. A common problem is that orientation can be good for some clients but may not be not optimal for others.

Telling Antennas Apart

One of the most important skills a WLAN engineer (or anyone who works with Wi-Fi networks) can have is being able to distinguish antenna differences. Not all antenna types work or perform the same way. The easiest way to compare antennas is through the characteristics just discussed: signal gain, direction and polarization. Another key piece of information are antenna patterns (also called polar plots) such as the E-Plane plot we used earlier *(see Figure 5, next page).*

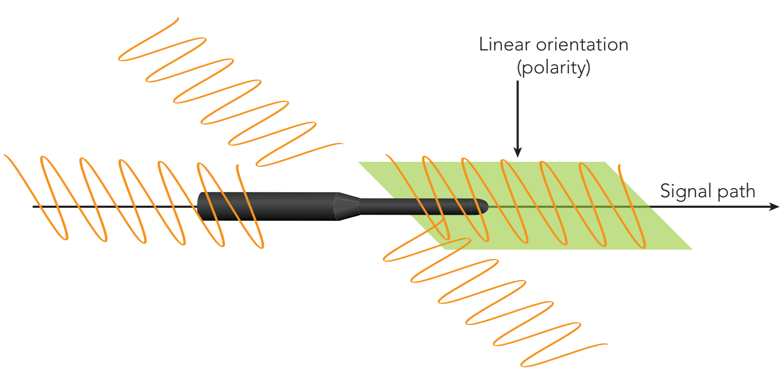
Fun with Antennas

Figure 6 *(next page)* shows an omni pattern plot. The red line is nearly a perfect — but not quite — circle. The 3 dB (half-beam width) angle of greatest direction for this antenna is close to 360° in the H-Plane. But the E-Plane (left) makes it obvious this is an omni antenna with relatively high gain — 9 dBi in this case.

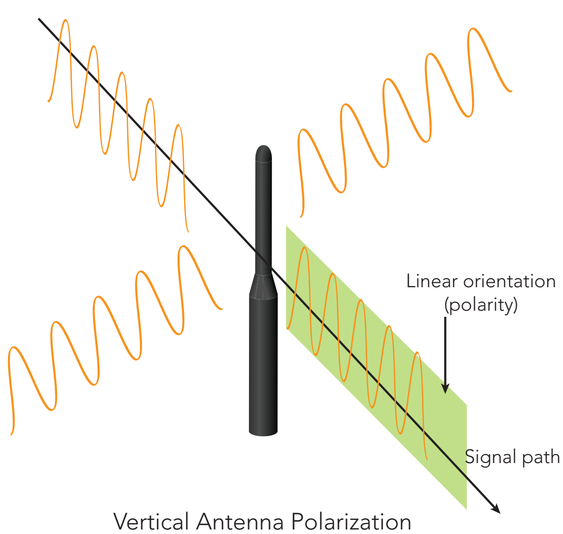
The E-Plane plot shows the 90° rotational view of the same pattern. Where the H-Plane was looking "down" onto the top of the antenna, the E-Plane is looking at it from the side. The E-Plane shows a shape that is characteristically associated with omnidirectional antennas. Two main lobes that extend out from the middle and account for most of the RF energy transmitted. This is just like the doughnut example used earlier. Note however that some energy is still directed vertically.

Figure 7 *(next page)* shows plots for a dual-band antenna. The upper two are the E and H-Planes for 2.4 GHz and the bottom two represent 5 GHz. This is an omnidirectional antenna but the difference here is that the E-Plane (blue) for the 2.4 GHz and 5 GHz spectrum are not the same shape. The 2.4 GHz E-Plane (top left) is essentially two large lobes — in a 3D space

FIGURE 4: How polarization works

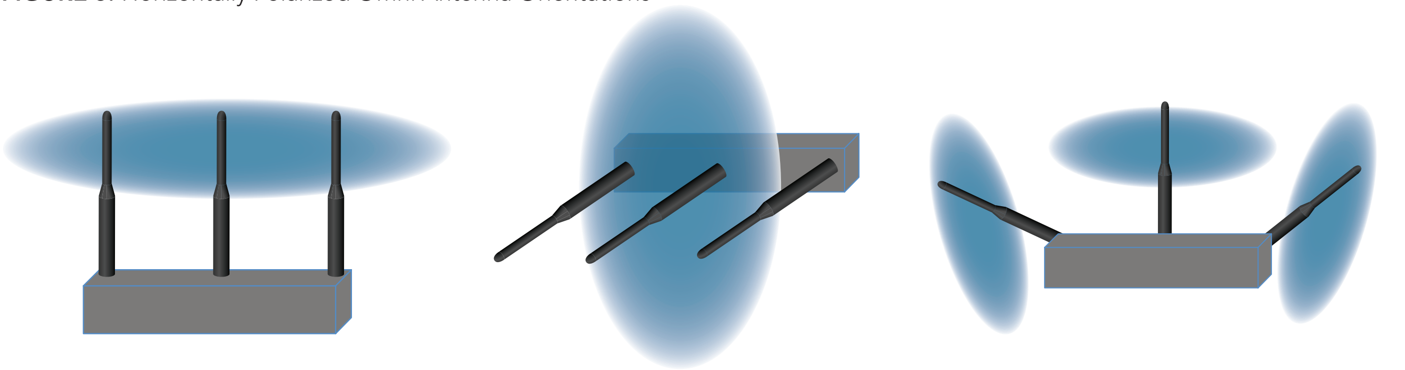


Horizontal Antenna Polarization



Vertical Antenna Polarization

FIGURE 5: Horizontally Polarized Omni Antenna Orientations



CORRECT
Orientation is mainly horizontal

INCORRECT
Orientation is mainly vertical

???
Who knows what they were trying to do here

this would be a cutaway from our doughnut shape. The 5 GHz E-Plane features two main lobes and four smaller ones — it has a higher gain and a different coverage pattern.

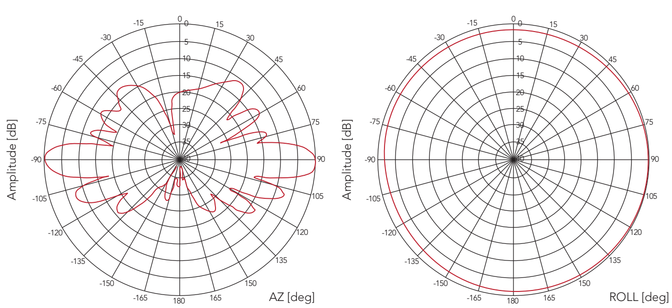
This example represents a single physical antenna housing with has two antennas inside; a 3.8 dBi vertically polarized antenna for 2.4 GHz and a 5.8 dBi omnidirectional for the 5 GHz range. It's not uncommon to see these kinds of antennas used by dual-radio/dual-band devices.

Interference

Interference — better yet, lack of it — is a critical component of Wi-Fi performance. The ultimate goal of a wireless transmission is to send a signal to another device, not necessarily transmit RF energy everywhere.

Any additional RF energy is generally referred to as interference, whether it is from an 802.11 device or not. When the transmission is on the same frequency (channel) as other Wi-Fi devices, this is co-channel interference. Co-channel interference can dramatically degrade Wi-Fi performance.

FIGURE 6: Omnidirectional Antenna Pattern



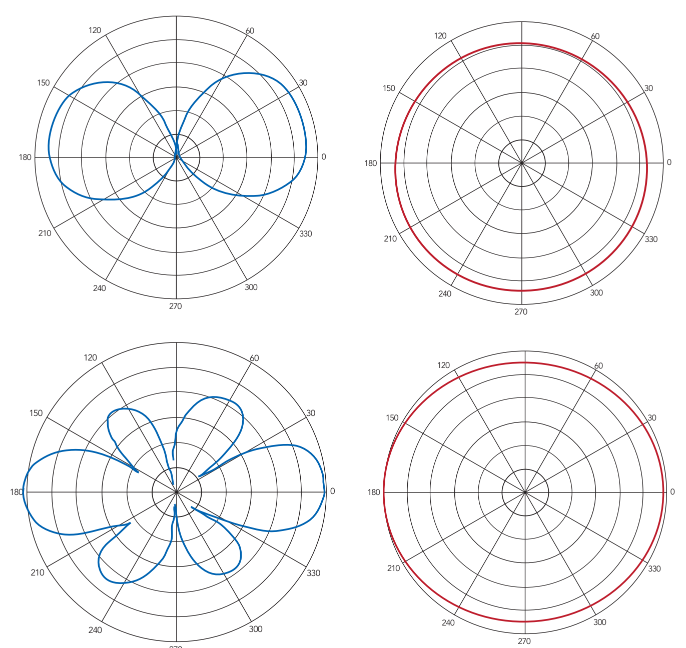
E-Plane

H-Plane

The reason is simple. 802.11 Wi-Fi is a half-duplex transmission technology; much like walkie-talkies. At any time, only one person can talk — all others can only listen until the first speaker is done and the channel is clear (silent). If two or more people try to talk at the same time, each transmission is garbled and no one can be understood. Wi-Fi works the same way.

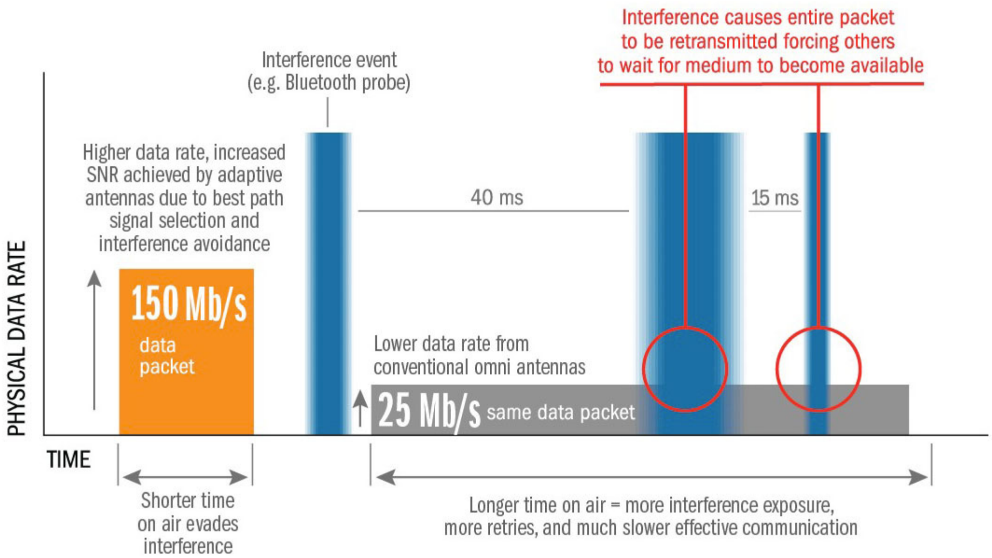
When one Wi-Fi client is talking to an AP, all other clients must wait for silence before they can transmit. If they don't wait, their transmissions will interfere with the first device. This will cause simultaneous transmissions (mid-air collisions) that result in corrupted packets and errors.

FIGURE 7: Dual-radio Antenna



Access points equipped with dipole, omni antennas have very little latitude (i.e. degrees of freedom) when dealing with interference. Interference causes packet loss, which forces retransmissions. This drives delays for all clients trying to access the medium. Access points unable to manipulate Wi-Fi signals typically lower their physical data (PHY) rate until some level of acceptable transmission is achieved (*see Figure 8*).

FIGURE 8: The Problem with Wi-Fi Interference - an Example

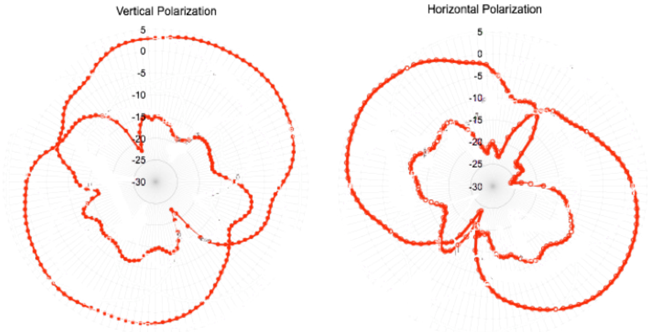


However this actually causes more problems — a slower the transmit speed means the same packet is in the air longer and therefore more likely to encounter to interference. Boosting the data rate and "steering" packets over signal paths that provide better SINR (Signal to Noise and Interference Ratio) helps solve this problem.

Ultimately, *(see table below)* RF issues tend to have the most significant impact client performance as measured by throughput.

PROBLEM	SOLUTION	IMPACT
360° coverage	Omnidirectional antenna	Unwanted RF, less signal strength/quality
Improved signal quality	Higher gain antenna and/or directional	Reduced range of coverage (no 360°)
Specific coverage orientation (spatially congruent with Wi-Fi device antennas)	Correct polarization and antenna orientation	It's all good
Reduce RF interference	Directional antenna	Reduced range of coverage (no 360°)

FIGURE 9



No Free Lunches

It seems like nearly everything is a trade-off (*see Figure 9*); an omnidirectional antenna provides 360° coverage, which is a good thing for clients clustered around the AP. But an omnidirectional gives up some distance (linear) signal quality and produces the most unwanted RF interference. A directional antenna, on the other hand, has better focus and distance with less unwanted interference. But it has limitations too — specifically it's not a very good choice to reach clients surrounding an AP in every direction; Wi-Fi devices tend not to congregate in nice 60° angles.

But everything learned so far could be used to design the ultimate Wi-Fi antenna – all RF physics aside — what might it look like? Ideally the antenna pattern will cover everything in a rough sphere of 3D space. Therefore the E-Plane and H-Planes should be fairly similar. However, since both horizontal and vertical polarizations are used, both polarizations need to be plotted and taken into consideration.

Ideally omnidirectional coverage is desired but with directional performance. That's precisely what smart antennas provide.

The omnidirectional antenna plotted (*see Figure 10*), is decidedly not a "pure" omnidirectional antenna. The RF patterns are "squashed" to achieve much higher signal gain. This leaves gaps in the coverage outside the primary lobes.

Another, similar antenna could be added that is turned 120° from the first. Coverage gaps in the first antenna's pattern are then covered by the primary lobes of the second antenna. This improves things greatly, yet there are still some areas that look a little weak — places that lie outside of both antennas' maximum coverage area. Adding a third rotated antenna helps even more (*see Figure 11*).

The vertical plot now has a nice omnidirectional smoothness on the outside as well as good focused coverage in each direction. So what's the benefit?

- An array that combines both horizontal and vertical polarization to match clients wherever they might be and however their antenna is oriented
- The basic coverage pattern is an omnidirectional (look at the outside lines)
- The antenna also offers directional antennas as well (the inside lines)

FIGURE 10

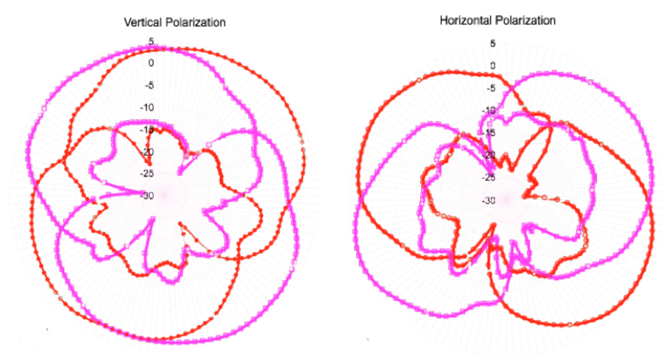
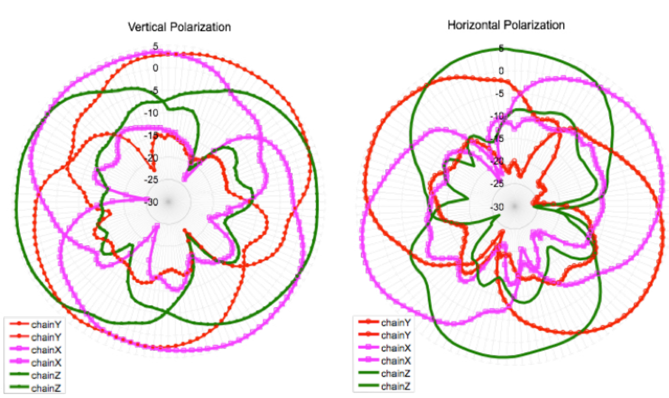
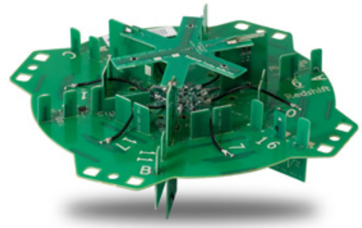


FIGURE 11



Ruckus BeamFlex

Adaptive, Multi-Element Antenna Array



This innovation approach to antenna design has been patented and popularized by Ruckus Wireless. It is designed to address all the criteria listed above with a clean solution that combines the best of antenna directionality, signal gain and polarization.

The miniaturized, adaptive antenna array is an elegant and revolutionary solution that has been in production and field-proven for over 7 years. The polar plots above represent the actual antenna patterns for the ZoneFlex 7962 dual-radio AP.

The antenna array shown above supports dual-radio usage and has 19 separate antennas. These antennas are directional and each element is either horizontally or vertically polarized. In all, the array is capable of over 4,000 different antenna combinations.

The antenna combination is selected via an optimization routine that learns through a packet-by-packet analysis of client traffic received. In effect, the antenna array dynamically creates a beam of concentrated RF energy that follows the client as it moves. The directional nature of this client connection ensures the highest performance with the least amount of extraneous RF interference to other devices. It also requires no client-side software or knowledge.

The omnidirectional nature of the antenna array is also used; it allows the AP to send beacons advertising itself (and receive client association requests) in a 360° pattern. The directionality is only engaged once a client has connected and starts sending data.

Of course this doesn't do any good if it only works for one client. An AP that can only support one client might make for great lab tests but would be useless in real-world deployments. BeamFlex optimizes the connection for every client and tracks the current optimization settings. Thus, the AP can continuously refine the connection for every client every time.

Adding Clients

IIn a linearly polarized system, a misalignment of polarization of just 45 degrees will degrade the signal up to 3 dB. A misalignment of 90 degrees can result in attenuation of over 20 dB.

This kind of issue is fairly easy to verify — just try moving a laptop around. Turn it 90° and run a throughput or signal strength test. Then turn it another 90° and try again. Or try flipping the screen of the laptop back and forward at different angles. Doing this often yields wildly different performance numbers, depending on the distance of the client from the AP and its antenna location and orientation.

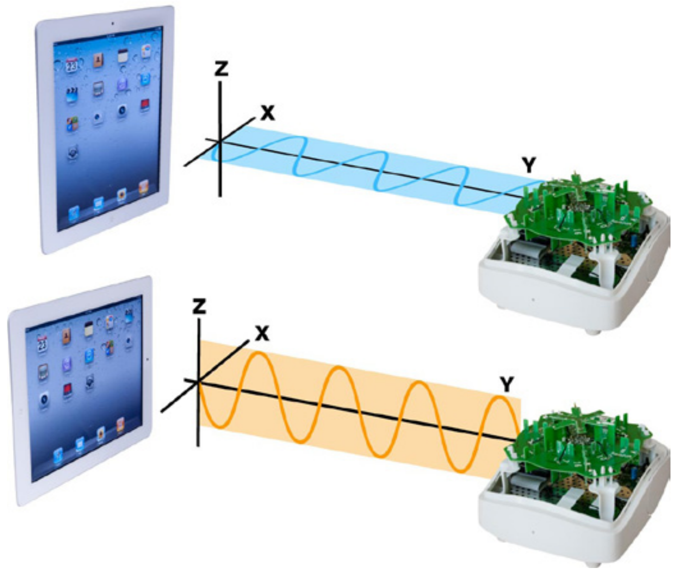
This makes perfect sense because clients have antennas too and those antennas must have some kind of antenna pattern associated with them. The closer the antenna patterns match up between two devices, the better the connection.

Ideally, the client's antenna should be as closely aligned with the AP as possible. This is often difficult to achieve as clients move around, occupying all kinds of heights, rotational positions, etc. Meanwhile APs are fixed devices, and don't have the option of physically moving with each client.

Nowhere is this more important than when trying to connect new, wireless-only, smart devices such as super phones and tablets.

These new handheld radio devices need APs with both horizontally and vertically polarized antennas (as discussed previously) for reliability (*see Figure 12*) and flexibility. Wi-Fi systems that employ adaptive, dual-polarized antenna arrays are the only way to get a signal to a client no matter where it is and how its oriented. Stronger, more stable Wi-Fi connections are key to greater client performance.

FIGURE 12: Auto RF Adaptation with Smart Antenna Arrays



Given the unpredictable nature of the Wi-Fi spectrum and interference, both a combined omnidirectional as well as directional coverage pattern make Ruckus' BeamFlex technology critical for the most reliable WLAN available today. The proof is in the RF physics.

Ruckus Wireless, Inc.
880 West Maude Avenue, Suite 101, Sunnyvale, CA 94085 USA (650) 265-4200 **Ph** \ (408) 738-2065 **Fx**