# Radios, Antennas, and Other Wi-Fi Essentials

Ruckus Wireless | Black Paper

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

### Wi-Fi Basics to Start

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 spectrums; either the 2.4 GHz or 5 GHz bands.

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 Wi-Fi radios are found in virtually every type of device imaginable.

The inevitable choice arises — 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 network, 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 technologies. Before performance metrics like TCP throughput can be discussed, the radio signal must be transmitted and received.

### Are All Radios the Same?

Radios are 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 what is the difference? What's the value-add that sets one AP apart from the pack?

The same chipset tends to provide the same performance for any vendor — all things being equal. But they aren't. Different implementations yield wildly 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 result in very different performance numbers.

Once an RF signal has left the AP's antenna there is nothing else the 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, how signals are sent and received has a dramatic effect on the stability and performance of a Wi-Fi network.

## An Antenna Primer

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

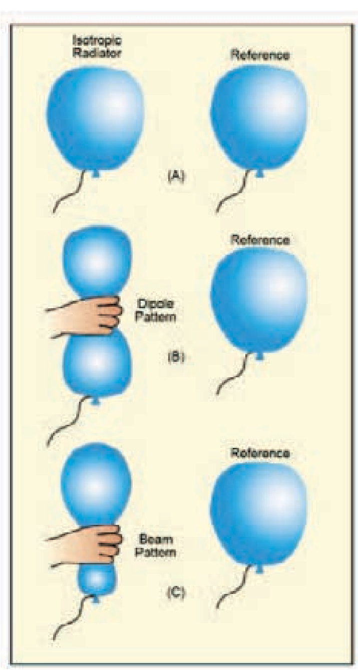
Gain is the amount of increased energy from an antenna focusing the RF signal. Direction refers to the shape of the transmission, which describes the coverage area. Polarization is the orientation of the electric field (*transmission*) from the antenna.

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

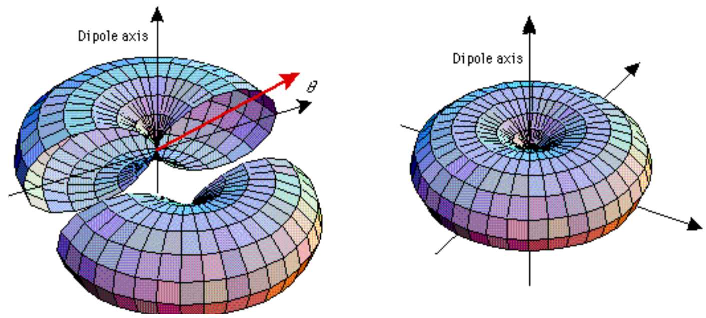
Conversely, a high-gain antenna typically transmits in a particular direction. Signal gain focuses the RF emission and improves signal quality, but it doesn't add power.




Think of it like a balloon. At rest, the air inside fills out the balloon uniformly. But squeezing one end of the balloon results in the other side getting larger as air is forced to one side. No matter how much pressure is applied, there will always be the same amount of air inside.

Better yet, imagine squeezing the balloon from below and above—you'll end up with a doughnut shape (*toroid*). This is essentially what an omnidirectional antenna's RF field looks like (*see Figure 1*).

**FIGURE 1:** 3D Omnidirectional Antenna Pattern




It's important to remember that antennas cannot add power to a wireless signal but can focus the RF energy. While the amount of energy will always stay the same, signal gain helps achieve longer distances, higher signal quality and faster data rates. Effectively, 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. Thus highest gain may not always be best.

Most omnidirectional antennas usually have around 2-3 dBi gain, with the goal of a more horizontal signal transmission. This is usually better for clients since they are usually oriented towards an AP horizontally, rather than vertically (Note: *this discussion of horizontal vs. vertical is about physical mounting/ orientation not polarization which is discussed later*).

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 plane *(See Figure 2, next page).*

### *Direction*

As discussed previously, an antenna has a certain amount of RF energy that can be focused through signal gain. Signal gain can also be achieved via changing directionality to an RF signal (i.e., *antenna sends more energy in one direction at the expense of another*). Even omnidirectional antennas have some small amount of signal gain which is why RF patterns are not a perfect spherical shape.

Directional antennas are used when signal is desired in a specific direction. A wireless bridge is a good example of when to use a directional antenna because the receiving end of the bridge is effectively fixed and won't move. So, instead of wasting precious RF energy transmitting to where the bridge is not located, push all of the RF transmissions in the right direction.

**FIGURE 2:** Longest and shortest signals for an omnidirectional antenna

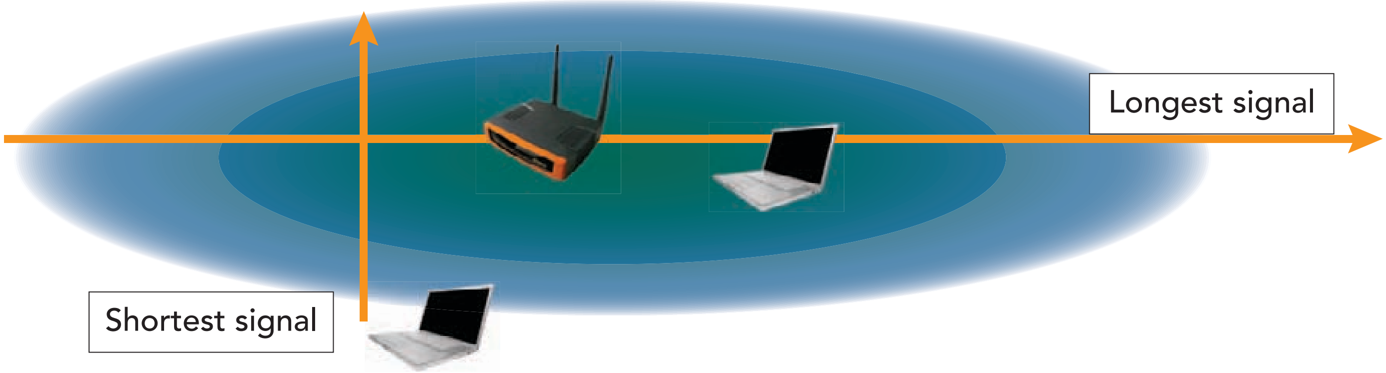
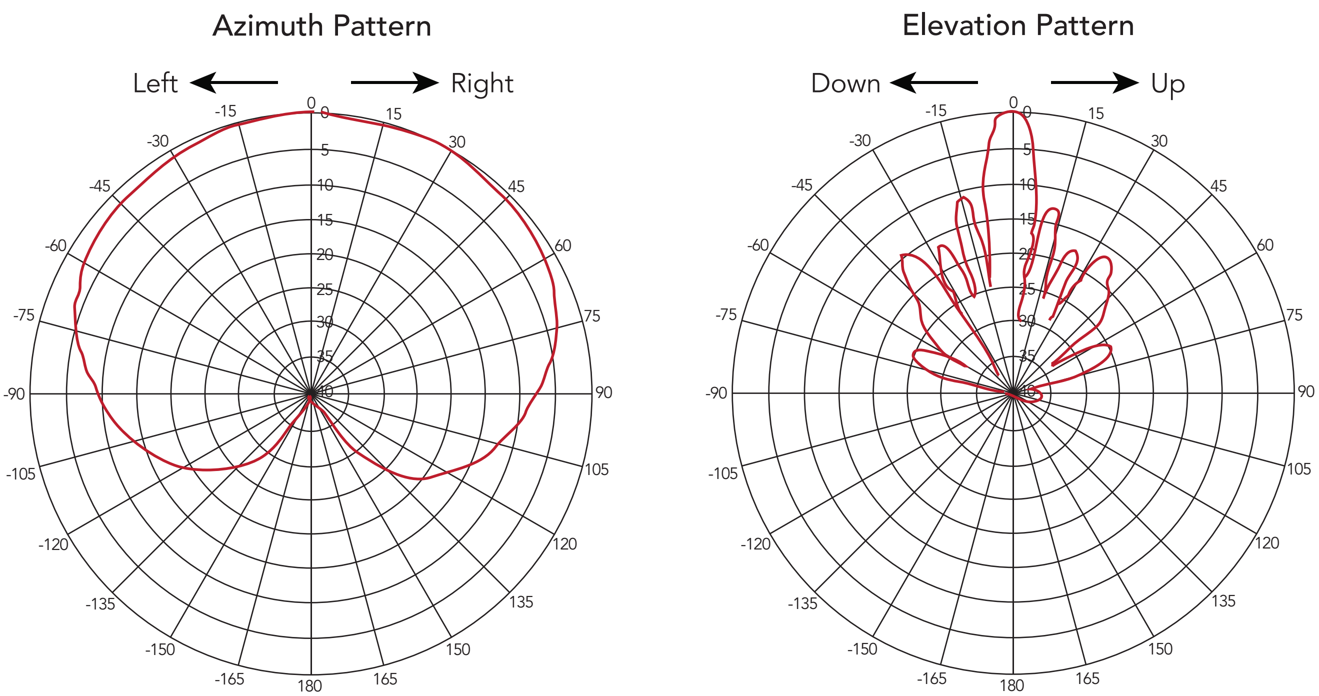



**FIGURE 3:** Polar plot of a directional antenna



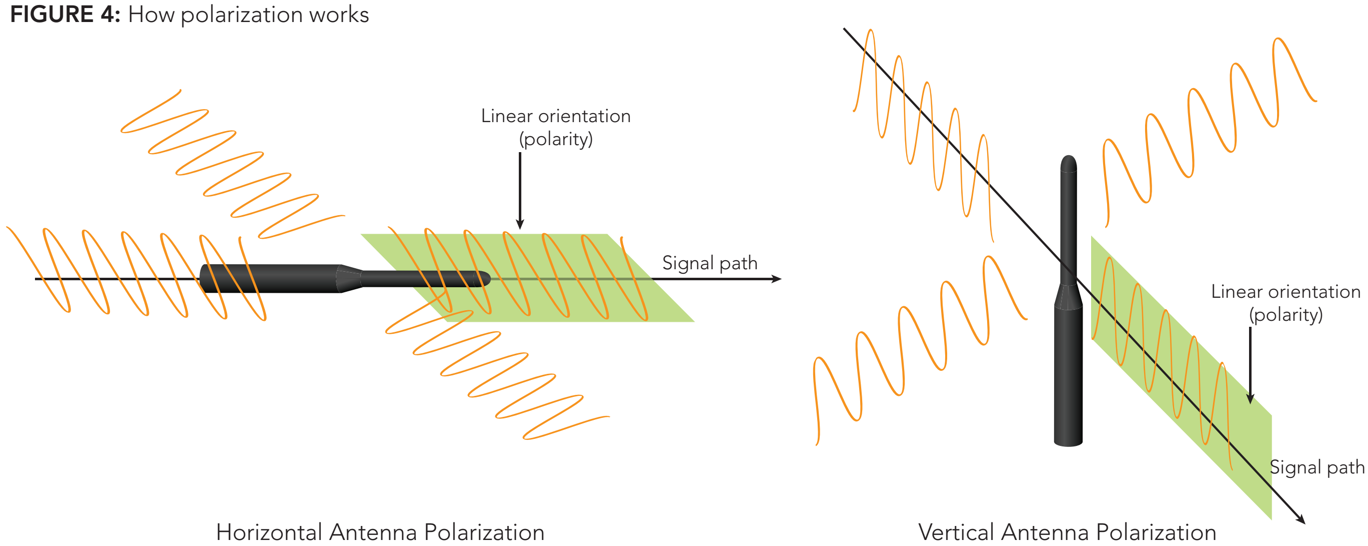

Consequently, the antenna will have a high signal gain as it focuses the energy and shapes it in a particular direction; understanding that RF is not transmitted in a perfectly straight line. Directionality doesn't mean that the signal is focused like a laser beam, but more like a cone. The energy will 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 directional antenna; this is a very common way of illustrating the coverage. The figure on the left depicts the azimuth coverage of the antenna.

The figure on the right illustrates the elevation plot. The primary beam is the largest shape. The next largest shapes, above and below the main lobe, are called side lobes (good antennas will *keep those small*). Meanwhile, the left figure shows the beamwidth which is approximately 150°.

The width of the beam is measured at half-power point or 3 dB below the peak. Each magnitude circle in the plot represents 5 dB and the rotational numbers along the outside of the circle correspond to the angle. If you look for the point where the red line is about three-fifths of the way from the outermost circle (*0 dB*) and the first circle inside (*5 dB*), you'll have the 3 dB beamwidth (*75° to the left and 75° to the right or 150°*).

**FIGURE 4:** How polarization works




### *Polarization*

Polarization is the orientation of the signal as it leaves the antenna. All antennas emit signals of one polarization or another. There are many different kinds of polarizations, however most Wi-Fi antennas are linearly polarized and will, generally speaking, 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 "rubber ducky" style antennas are usually polarized in one direction. It's important to understand how they are polarized so the antennas can be oriented to the proper position. A common problem is that orientation can be good for some clients but may not be optimal for others.

### *Telling Antennas Apart*

Being able to distinguish differences in antennas is an important skill for any engineer. 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 azimuth coverage plot we mentioned earlier (*see Figure 5, next page*).

## Fun with Antennas

Figure 6 (*next page*) shows an omni pattern plot. The red line is an almost perfect circle. The 3 dB (*half-beam width*) angle of greatest direction for this antenna is close to 360° in the azimuth plane. But the elevation plane (*on the right*) makes it obvious this is an omni antenna with relatively high gain — 9 dBi in this case.

**FIGURE 5:** Horizontally polarized omni antenna orientations

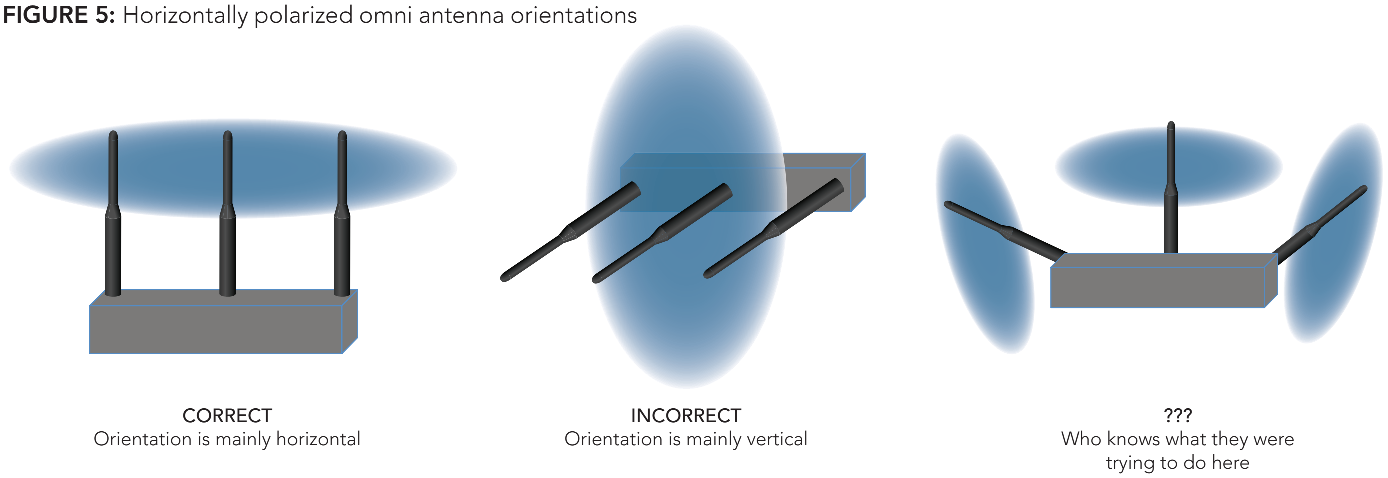
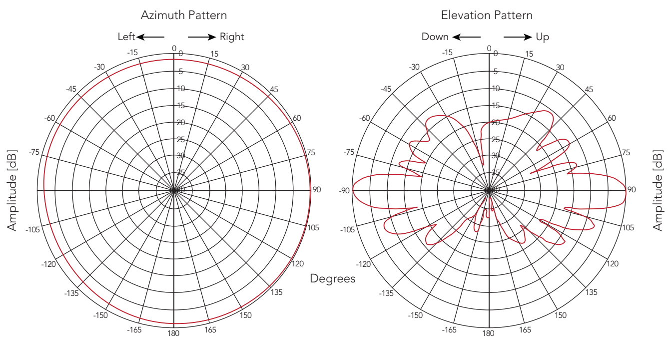


**FIGURE 6:** Omnidirectional antenna pattern




The azimuth plot shows the 90° rotational view of the same pattern. Where the azimuth plane looks "down" onto the top of the antenna, the elevation plane is looking at it from the side. The elevation 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 that some energy is still directed vertically.

Figure 7 shows plots for a dual-band antenna. The upper two are for 2.4 GHz and the bottom two represent 5 GHz. This is an omnidirectional antenna but the difference here is that the azimuth (*blue*) for the 2.4 GHz and 5 GHz spectrum are not the same. The 2.4 GHz elevation (top left) is essentially two large lobes — in a 3D space this would be a cutaway from our doughnut shape. The 5 GHz elevation pattern 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, or 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 creating a 'radio fog'.

Unwanted 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.

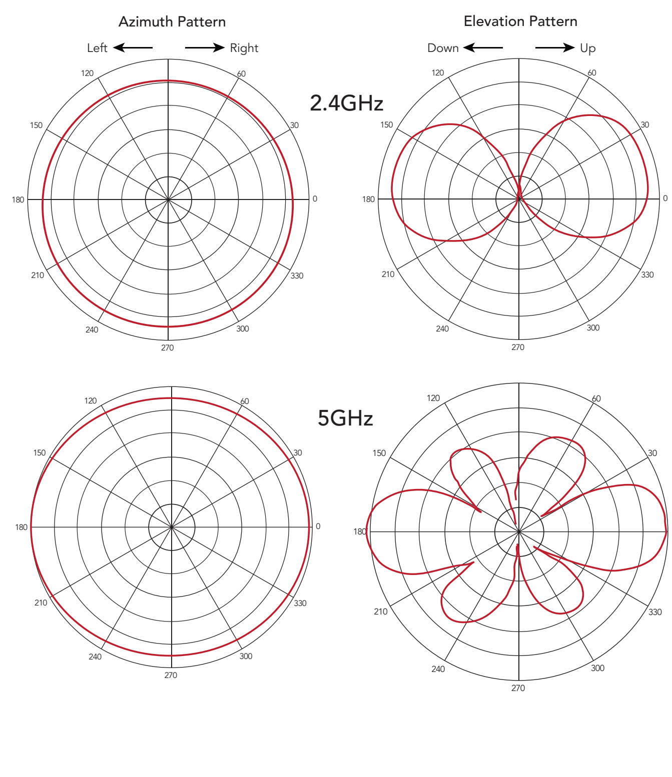
The reason is simple. 802.11 Wi-Fi is a half-duplex transmission technology, much like walkie-talkies, at any time only one person can speak — all others can only listen until the channel is clear (*silent*). If two or more people try to talk at the same time, each transmission is garbled and no one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

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.

Access points equipped with dipole, omni antennas have few degrees of freedom, when dealing with interference. Interference causes packet loss, which forces retransmissions, that 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*).

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

**FIGURE 7:** Polar plot of a dual-band antenna



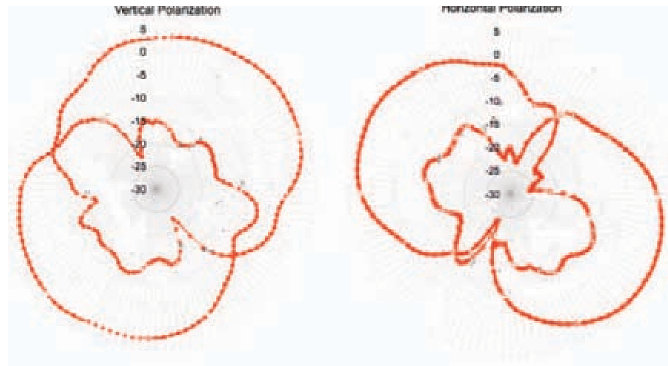
Ultimately, *(see table below)* RF issues tend to have the most significant impact on client performance as measured by throughput.

| 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°) |

## 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.

**FIGURE 9: :** Polar plot of single radio chain (5GHz)



However, lessons learned thus 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. And 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, which is precisely what smart antennas provide.

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

**FIGURE 8:** The problem with Wi-Fi interference - an example

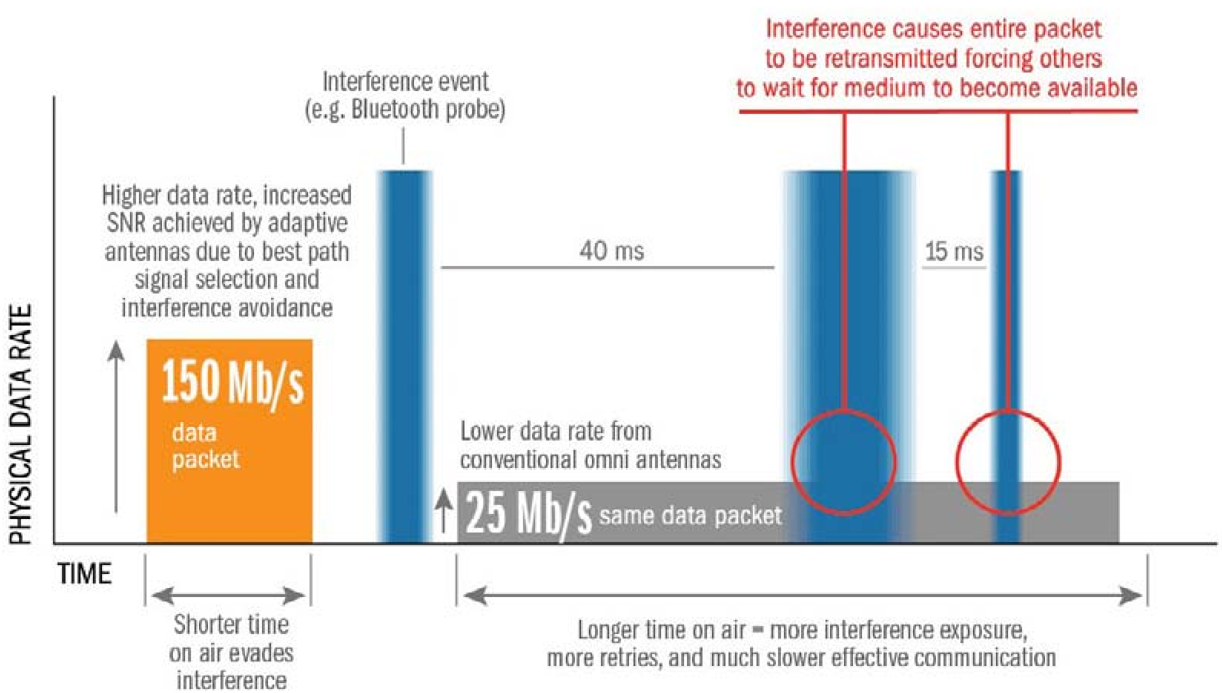


**FIGURE 10:** Polar plot of 2 radio chain (5GHz)

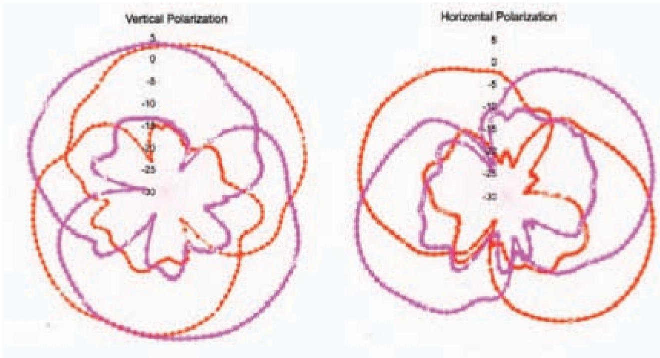
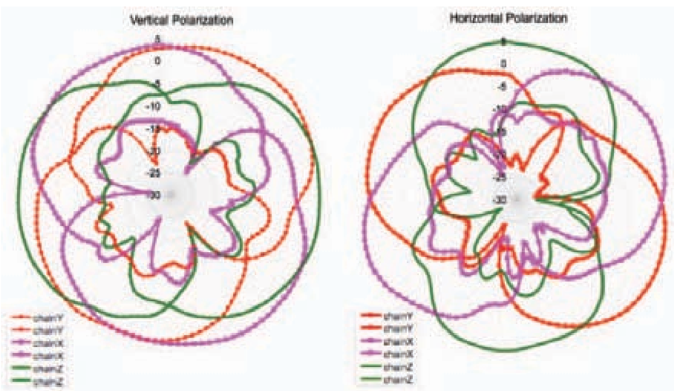



**FIGURE 11:** Polar plot of 3 radio chains (5GHz)



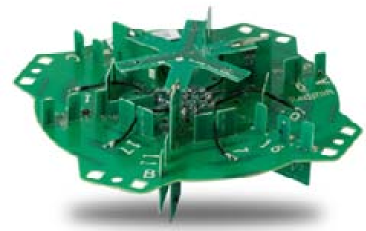

Another similar antenna could be added that is turned 120° from the first. Coverage gaps in the first antenna's pattern are then covered by the primary lobes of the second antenna, this greatly improves performance, yet there are still some areas that look a little weak — places that lie outside of both 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)

## Ruckus BeamFlex

**Adaptive, Multi-Element Antenna Array**



This innovative approach to antenna design is at the heart of Ruckus Wireless RF technology. The Ruckus multi-element antenna array (BeamFlex), is designed to address all the criteria listed above with a 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 Wi-Fi expertise.

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 on a per packet basis.

### *Adding Clients*

In 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.

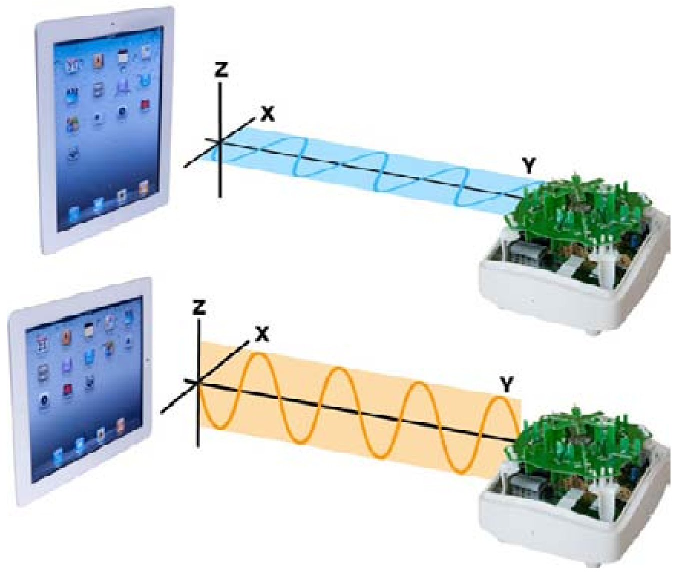
This kind of issue is fairly easy to verify — just try moving a laptop around. Turn it 90° and run a throughput or signal strength test, then turn it another 90° and try again, or try flipping the screen of the laptop back and forward at different angles. Doing this can yield different performance numbers, 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 polarization and 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, which 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 it's oriented. Stronger, more stable Wi-Fi connections are key to greater client performance.

**FIGURE 12:** Dual polarized, adaptive antenna array




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.

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