



white paper

BeamFlex, 11ac Wave 2, and MIMO: The art of RF engineering

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The world of RF has always been a bit of a black art as there are so many variables that go into determining the throughput of any wireless connection. It often starts with a discussion of the frequency band used, channel width, environmental factors, signal-to-noise ratios, obstructions, interference, even rain can make a difference in the higher bands. And as if that wasn't enough, in the past few years we've seen a move to some very sophisticated antenna technologies, and to a large extent RF performance depends largely on antenna technology. In this paper we'll take a closer look at the fine art of antenna design. There are many variables here, and we'll start by looking at how antennas radiate RF energy.

Antennas can be designed to radiate RF energy omni-directionally or they can use adaptive antenna technology to direct greater amounts of RF energy toward the intended recipient. There are also access points with fixed directional antennas that are used for a variety of special applications. The omni-directional approach is very simple and very common but also very limited in that they radiate RF energy equally in all directions. The best example of adaptive antennas in the Wi-Fi market is Ruckus BeamFlex technology. Let's start with a definition of BeamFlex.

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What is BeamFlex:

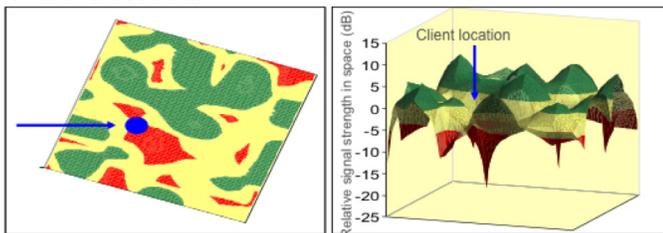
BeamFlex is a standards-agnostic (can be used with Wi-Fi, LTE or any future wireless standard requiring antennas and software) suite of machine learning software and antenna control hardware, which maximizes application layer throughput. BeamFlex works on top of any standards based transmit beamforming (TxB) approach and delivers the highest available throughput by adapting each individual antenna's radiation pattern(s) together with physical data rates thereby minimizing interference by getting clients on and off the airlink faster and thus increasing overall system capacity.

By customizing the antenna pattern for each user and each packet, BeamFlex can deliver up to a 6 dB of additional gain as seen by the user's device. 6 dB in RF parlance means a signal that is four times stronger than what you'd get with an omnidirectional antenna. It is important to note that BeamFlex does not change the amount of energy that radiates from the access point, as that is set by regulation, only the amount that the client receives. BeamFlex makes a huge difference in congested and high interference environments, which makes adaptive antennas essential in train stations, airports, convention centers, downtown city center, stadiums, etc.

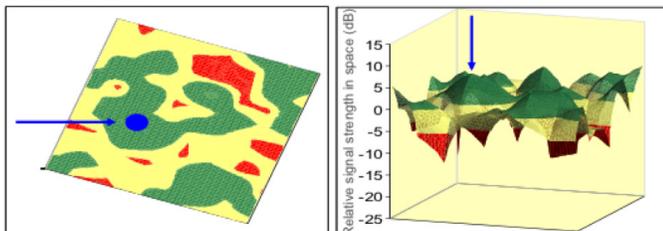
Adaptive antennas certainly play a huge role in increasing RF performance, but what else can we do here? One of the easiest ways to increase RF performance is with wider channels, and this is made possible with channel bonding.

Figure 1: BeamFlex alters the antenna pattern for each and every packet transmitted to provide increased gain (by creating signal peaks) at the user's device

Omnid antenna



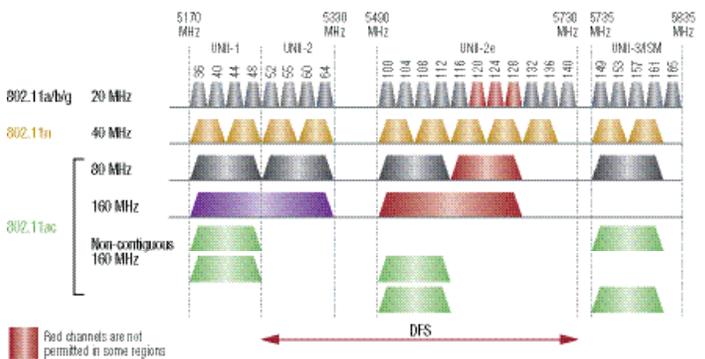
BeamFlex



Wider Channels

Nothing cranks up performance quite as effectively as wider channels, as throughput increases linearly with channel width. One way to increase channel width is with channel bonding, which combines two or more 20 MHz channels into one transmission. In the cellular world this is done with carrier aggregation using LTE-Advanced technology, which runs over licensed spectrum. The big challenge with channel bonding in the unlicensed bands is to find 2, 3, or even 4 channels that aren't being used at that particular point in time, and these must be adjacent channels. Channel bonding also reduces the number of non-overlapping channels that are available at that location, and in high-density applications you can never have enough non-overlapping channels. This is described in more detail in the following drawing.

Figure 2: Channel bonding provides very wide channels, but there are fewer of them



A separate issue with wider channels is that a radio's transmit power is spread over more total bandwidth, reducing power density per unit of frequency. This is an issue if the access point operates at the maximum transmit power level allowed by regulation. This may sound obscure but what it means is that if the AP radiates 30 dBm over a single 20 MHz channel then when operating over two 20 MHz channels, each channel can only radiate 27 dBm (this assumes that 30 dBm is the most allowed by regulation).

MIMO Antennas

MIMO technology uses spatial multiplexing to take a high-rate data stream and split it into multiple low-rate data streams, with each data stream being transmitted from a different transmit antenna in the same channel. If these signals arrive at the client's antenna with sufficiently different spatial signatures, the receiver can separate these streams into (almost) parallel channels. BeamFlex antennas do a very good job of providing great spatial separation. Spatial multiplexing is a very powerful technique for increasing channel capacity at high signal-to-noise ratios

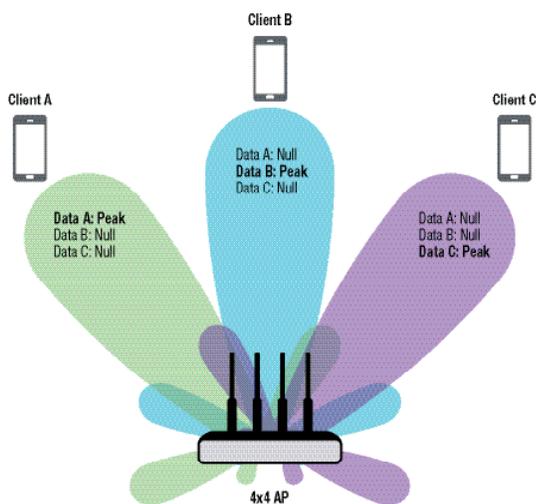
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(SNR). The maximum number of spatial streams is limited by the lesser of the number of antennas at the transmitter or receiver. This means that MIMO isn't as effective with smartphones as these are mostly single stream devices, but having multiple transmit antennas still helps quite a bit. The real power of MIMO comes when using laptops that support multiple spatial streams or in point-to-point applications which have an access point on each end. While single user MIMO is very powerful, things get really interesting when we move to multi-user MIMO in 802.11ac.

Multi-User MIMO

The potential benefits of MU-MIMO technology are very exciting. First, access points typically have several additional spatial streams as compared to smartphones, which only have 1 or at most 2 streams. MU-MIMO utilizes those extra streams more effectively by allowing the access point to talk to more than one client at the same time. MU-MIMO is a downlink only technology, and all uplink transmissions are "single user". MU-MIMO can multiply downlink AP capacity by a factor of 2 or 3 under the right conditions. The following figure shows a 4x4 AP that uses MU-MIMO to communicate with three 1x1 mobile clients—note that MU-MIMO requires client support. Without MU-MIMO these mobile clients would have to be served sequentially by the access point, but now all three can be served at the same time. So how exactly does MU-MIMO work, and how does it work with adaptive antenna technology?

Figure 3: MU-MIMO uses Transmit Beamforming to provide feedback as to how to increase gain at the intended user's location, while at the same time notching that signal for other users in the group.



Let's use the example of a three-stream access point. Each of the three streams is targeted at a different client device. This is very different from standard MIMO where all three streams are intended for the same client device. The transmitting of three different streams to three different clients over the same channel at the same time from the same access point would normally cause interference. In fact the interference would be so severe as to make communications impossible. Now we get to the magic of multi-user MIMO. A key enabling technology here is chip based transmit beamforming (TxB). Note this is very different from BeamFlex, and we'll get back to that later. TxB provides feedback from the client to the access point on how to modify the transmission so as to deliver a stronger signal at the client's location. This is hugely valuable to the access point as it tells the AP not just how to maximize the signal as seen by the intended user, but how to minimize that signal as well. This transmission constitutes crippling interference for the other two clients that are each receiving on a different stream. The AP then takes the information on how to maximize the signal at client "A" along with the information on how to minimize signals arriving at clients "B" and "C" and uses this to construct a transmission to client "A" that is largely invisible (notched) at clients "B" and "C", but still comes across as very strong to client "A". Information on how to notch or null a signal at a certain point can be determined if you also know how to maximize the signal at that point.

MU-MIMO and BeamFlex

If the clients are grouped appropriately this can be very effective. So how does BeamFlex play in a MU-MIMO application? The notching can enable a good SINR (signal to interference plus noise ratio) as seen by the client's device. BeamFlex can increase this by up to 6 dB to make it a very good SINR. This enables much greater throughput because it allows a better MCS (modulation and coding scheme) to be used. So not only can the MU-MIMO access point transmit to three or more clients at one time, it can do it at a very high speed by leveraging the performance improvement that come with BeamFlex. Transmit Beamforming and BeamFlex are two very different RF technologies that come together for maximum benefit with multi-user MIMO.

MU-MIMO capable access points can provide a greatly enhanced user experience for MU-MIMO capable smartphones. It can also provide a greatly enhanced user experience for non MU-MIMO smartphones simply by operating in a standard MIMO configuration using the greatly enhanced silicon that comes with the new MU-MIMO technology.