Engineering Notes – Range and Line-of-sight

Like any Ultra-High-Frequency (UHF) radio device, WiFi in general and the AyrMesh Hub in particular depends good line of sight between the antennas of the devices in the network. Although the radio waves behave very much like light, they do not behave exactly like light, and the differences are important.

Glossary

AyrMesh Hub – The basic wireless mesh node in an AyrMesh network.
Client – any WiFi device on the network.

Introduction

As the frequency of radio signals increases, they behave more and more like light. In particular, they go in relatively straight lines from transmitter to receiver, and anything that blocks that straight line diminshes the strength of the signal and, therefore, the range.

To counteract that, the AyrMesh Hub uses the highest power allowable by law and a powerful antenna to "focus" the radio energy out toward the horizon.

Antenna Orientation

One of the most important features of the AyrMesh Hub is the high-gain omnidirectional antenna. A "normal" WiFi router/access point has a 2 deciBel (dB) antenna, which transmits the signal in every direction almost evenly: out to the walls of the room, up to the ceiling, down to the floor, etc. The 6 dB antenna on the AyrMesh Hub, on the other hand, "compresses" the signal into a narrower band radiating from the sides of the antenna to provide a stronger signal :

Radiation pattern,
2 dBi antenna

Radiation pattern,
6 dBi antenna

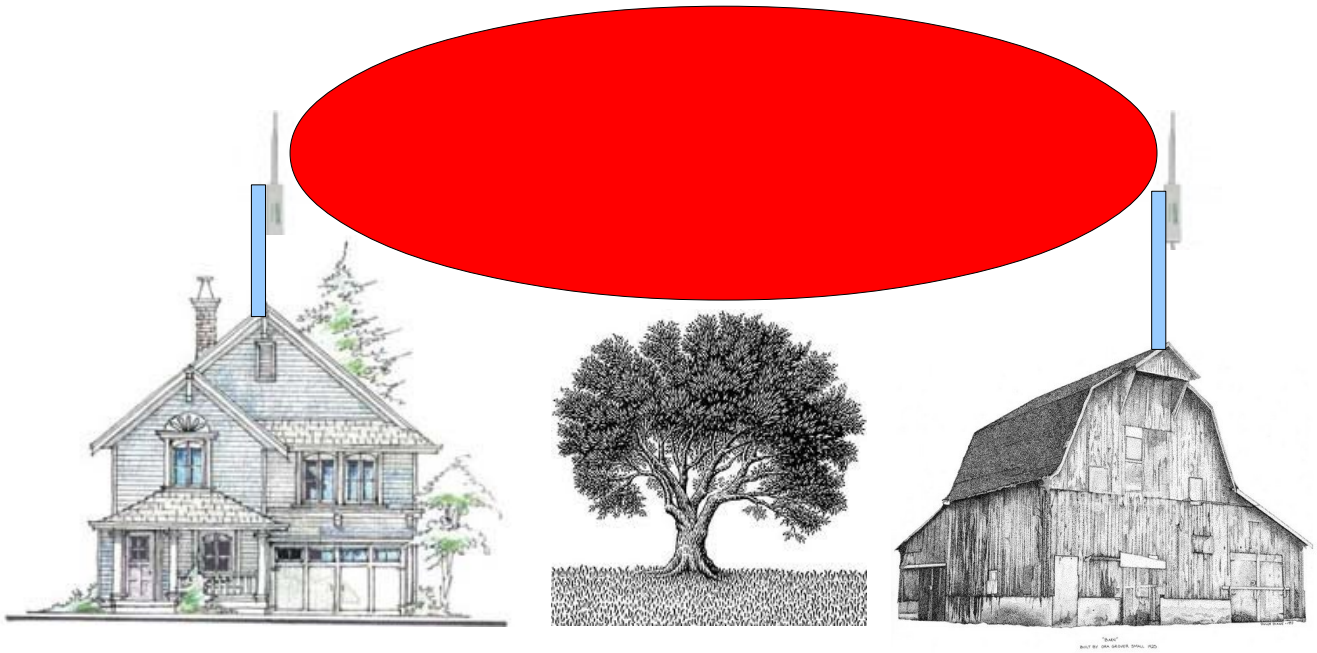
This radiation pattern gives the Hub the best possible range outdoors (it is important to note that antennas have the nice property that they “listen” as well as they “shout,” so the big antenna on the Hub also improves the performance of your laptop, tablet, or WiFi smartphone) but ONLY works well if the antenna is pointed straight up in the air. It may be useful to think of the AyrMesh Hub as being like a camping lantern – lots of “light” out to the sides, less above and below it. If the antenna is tilted, of course, the pattern will be skewed with one side “shining” into the ground and the other up into the sky.

Fresnel Zone

You might recall from the introduction that I said that UHF radio signals travel in “relatively” straight lines. The signals actually travel in a football-shaped volume from transmitter to receiver called the “Fresnel Zone.” You can read more about the Fresnel Zone on the internet (Wikipedia has a very good article about it), but it is best described as the volume that would result if you took a football, pumped it up until it was very wide, and then stretched the ends between the two radio stations you're considering.

Anything that gets between the two radios (e.g. the AyrMesh Hub and your laptop) diminishes the strength of the signal. The amount by which the signal is diminshed depends on what the material is and how much of it is there. For instance, air and glass are relatively “transparent” to UHF radio signals, but wood (trees, walls) diminish the signal strength a lot, brick, stone, and concrete even more, and radio signals generally don't travel through metal at all.

The trick is to have that Fresnel Zone as clear as possible to ensure good contact between the two radios. Ideally, you keep the Fresnel Zone 80% clear, but 60% is generally considered the minimum. An example is shown below in red:



A key factor is how wide the middle of the Fresnel zone is, and that radius is given by the formula 36.03*sqrt(d/2.437), where d is the distance between the two radios in miles (2.437 is the frequency of WiFi channel 6 in Gigahertz). So, if the two radios are a mile apart, the radius of the Fresnel Zone is 23.1 feet, and you want to have the imaginary line between the two radio antennas at least 23.1 feet above anything standing between them. Note that, at 2 miles, the Fresnel Zone grows to 32.6 feet, while at half a mile it is only 16.3 feet.

This can be a bit tricky, of course: remember, the Fresnel Zone is 3-dimensional; while one usually thinks of things intruding from the bottom of the zone (trees, corn, etc.) note that there can be intrusions from the sides or even the top.

Where this gets very odd is with two hubs that are just “peeking” over an obstacle like a hill. Even though you can get up on a ladder and, sitting next to the Hub, see the other Hub “peeking” over the hill, the Hubs may not be able to maintain a solid connection because the Fresnel Zone is about 50% obstructed by the hill. On the other hand, you may have a tree that is obstructing the line-of-sight, but not enough to prevent the Hubs from having a solid connection because 60% of the signal can “filter” through the leaves. So line-of-sight isn't necessarily line-of-sight.