Wi-Fi Isn’t Magic – the Laws of Physics Still Rule

White Paper

Reliable Communications for a Wireless Future

Wi-Fi started out as a novelty item for coffee shops and small offices. The firmware was buggy, performance was weak and vendor interoperability was problematical. Wi-Fi devices were designed to be used in safe home and office environments and they couldn’t stand up to shock, vibration or temperature extremes. Wi-Fi was also vulnerable to EMI and competing radio interference, which often led to data loss and blue screens in off-the-desktop scenarios. Wi-Fi was a great convenience in the right situations, but it didn’t provide the level of rugged reliability required for serious industrial applications.

We’ve come a long way in a very short time. Wireless software and hardware have both improved dramatically. The 802.11n Wi-Fi standard already provides throughput and reliability that rival 100 Mbps Ethernet while simultaneously creating opportunities to make connections in places that cable couldn’t reach.

But let’s not get carried away. Every technology has its limitations, and no matter how good it gets, it still has to obey the laws of physics. Wi-Fi is no exception.

The Problem with Modulated Electromagnetic Waves

Wi-Fi does some amazing tricks. While drinking your morning coffee you can monitor a remote web cam, stream video or telecommunicate with a customer at the other end of the country. Wi-Fi will cross highways and rivers, it will cover an entire campus and – depending upon the frequency – it can be quite good at penetrating walls and ceilings. In one sense, Wi-Fi is as close to the cutting edge as a technology can get.

But, new software and hardware aside, Wi-Fi still depends upon technology that is more than a century old: modulated electromagnetic waves, or radio. And while we’ve certainly come up with many ways to use radio, from microwave ovens and cell phones to garage door openers and the key fob that locks your car, it’s still radio. And it’s still subject to the same limitations that existed in Marconi’s day.

Wi-Fi devices currently broadcast over the unlicensed 915 MHz, 2.4 GHz, and 5.800 GHz radio bands. If nothing interferes, a radio signal will attenuate with the square of the distance. Halving the range will decrease path loss by 6 dB. Doubling the range will increase path loss by 6 dB.

But different radio frequencies behave differently in different environments. The higher the frequency, the more easily radio waves are absorbed or reflected by things like ordinary building materials and vegetation. Visible light, though far higher up the electromagnetic spectrum, demonstrates the principle nicely. A sheet of typing paper will let some light through, but a ½ inch piece of plywood will block it entirely. Radio waves behave in a similar fashion. They have much better penetration than visible light, but you wouldn’t bother trying to pick up the Cubs game if you were working in a bank vault.

Because higher frequencies are more easily reflected, they produce more multipath propagation, a phenomenon that occurs when transmitted signals bounce off an intervening object – even ordinary raindrops. The reflections cause different parts of the signal to arrive at the receiver at different times, and out of sequence. The worse the multipath propagation becomes, the more the signal begins to merge with the noise floor. Early Wi-Fi devices couldn’t sort things out.

So although attenuation may look the same on paper, real world conditions like multipath propagation meant that Wi-Fi at 2.4 GHz could be expected to have greater range than Wi-Fi at 5 GHz. And 900 MHz could be expected to do even better. A 900 MHz GHz installation would have roughly 8.5 dB less path loss than a similar 2.4 GHz installation.

If frequency and multipath propagation were the only concerns, low frequencies and would seem to confer great advantages. But as frequency drops, so does bandwidth. As an extreme example, the Extremely Low Frequency (ELF) communications systems developed by the US and Russian navies can reach submarines under several hundred feet of water. But, due to the very low frequency employed, the systems can only transfer data at a rate of a few characters per minute. Their primary use is to ask the subs to rise to a more shallow depth and employ some faster means of communication. (And, because a broadcasting antenna must be at least a fraction of the radio signal’s wavelength, a submarine can’t use the ELF system to answer back. The lower the frequency is, the larger the antenna must be to achieve useful gain. There’s no room on a sub for an antenna of the required size.) A less extreme example of the drop in bandwidth would be 900 MHz license-free radio vs. 2.4 GHz. 900 MHz may penetrate obstacles more efficiently, but
it provides less bandwidth and requires a proportionately larger antenna and more power to produce the same gain.

So 2.4 GHz would seem to be a nice compromise; more bandwidth than 900 MHz, less multipath propagation than 5 GHz. But Wi-Fi isn’t the only thing using the license-free 2.4 GHz frequency. Microwaves operate at 2.4 GHz, as do countless other devices like cordless telephones and remote control toy airplanes. Each of these devices will interfere, to some degree or another, with any other device that happens to be within range. And as the most popular of the license-free frequencies, 2.4 GHz is becoming over-saturated. That’s not an issue for a low power, short range device like a key fob. But what happens when you’re trying to establish reliable network connections, with good connection speeds, in off-the-desktop applications?

**Going With the Flow**
Wi-Fi developers have made great gains by adapting to the behavior of radio, rather than trying to fight it. For example, the current 802.11n Wi-Fi standard provides for the use of multiple input multiple output (MIMO) technology. Instead of becoming confused by multipath propagation, MIMO devices expect it. They employ multiple antennas at both the transmitting and receiving sides of the wireless connection, and they split the data into numerous spatial streams. The streams are transmitted through separate antennas and collected by corresponding antennas in the receiving devices, where onboard software uses signal processing algorithms to correct and interpret the incoming data. Approached this way, multipath propagation isn’t a problem anymore. In fact, it’s actually quite useful.

MIMO 802.11n devices also employ precoding and postcoding techniques like spatial beamforming to help them understand one another. In spatial beamforming a transmitter modifies the phase and relative amplitude of the signal in such a way as to create a pattern of constructive and destructive interference in the wavefront, making it easier for the receiver to interpret incoming signals.

Additionally, 802.11n adds frame aggregation to the MAC layer. By grouping several data frames into a single, larger frame, 802.11n allows management information to be specified less frequently, which means that the ratio of payload data to total data volume is higher, allowing for better throughput. The 802.11n standard also adds 40 MHz channels to the physical layer (PHY), doubling the bandwidth that was available in the older 20 MHz standard.

Because MIMO technology incorporates multiple radios and multiple antennas, its power requirements would be higher than those for devices with a single transmitter and receiver. So data is transmitted in bursts. During idle periods MIMO circuitry can make itself inactive, reducing the need for power.

By using new hardware and software to work within the rules of radio, rather than against them, 802.11n has proven to be a dramatic improvement over earlier 802.11 standards. But 802.11n is only the beginning.

**What’s Next?**
The advent of digital television broadcasting has freed up radio frequencies below the 700 MHz range, opening up new, unlicensed territory for use by new radio devices. At the same time, there’s still plenty of room for growth and innovation in the higher frequency ranges. Receive sensitivity is a function of the transmission baud rate so, as baud rate goes down, sensitivity gets better. Higher frequencies have more bandwidth, so there will be opportunities to fine-tune the balance between baud rates and receive sensitivity. Enhanced receive sensitivity increases range.

And ongoing improvements in integrated circuits, micro-power and power harvesting will allow devices to become smaller and smaller as their innate capabilities grow. Software and hardware will continue to become more sophisticated, and all of these trends will come together to trigger a wave of wireless innovation that will dwarf anything that has come before. You’ll soon be able to network-enable just about any device over a wireless connection. From M2M to streaming video, it’s going to be a wireless world.

But no matter how sophisticated Wi-Fi becomes, the physical laws of radio will remain the same. To be sure, you’ll be able to communicate with remote devices that are many kilometers away. But you still won’t be able to pick up the Cubs game in that bank vault.