Wireless Technology and Standard : Wireless LAN Standards

Bogdan Doinea (23 mins)

Now that we've covered the Carrier Sense Multiple Access / Collision Avoidance techniques, along with offering you the understanding of different channels that you can split an ISM band into, then we are perfectly equipped with both the physical knowledge of understanding how electromagnetic waves work based on frequency modulation, and how we can split different frequency into channels to actually understand the way the wireless standards use these things to achieve communication.

Let's look at the grandfather of all wireless standards in the LAN. 802.11 - this was released in 1997, this is considered the legacy standard. It was specified in infrared and wireless. It was using the Spread Spectrum technology in terms of modulation. The abbreviation there, comes from Direct Spread Spectrum and Frequency Hopping Spread Spectrum, which is a technology that is embedded inside 802.11 that is used in other technologies that enable the signal to basically detect the signal-to-noise ratio in a specific frequency, and jump to another frequency within that same channel if that is available.

The speed, however, is quite low: 1 to 2 Mbps, and remember, this is a theoretical speed - remember our discussion about the Request-to-Send, Clear-to-Send and about the Acknowledgements? So definitely the actual throughput would be around the 600-700 kbps if you're lucky. Of course, the speed varies towards the 2 Mbps if you're right next to the Access Point. But if you’re going to go further and further away from the equipment, we're going to get lower and lower data rates which is kind of intuitive, and at a certain point, data rate is going to be so low you're not even going to be able to associate to the Access Point into the WLAN anyway.

In terms of frequency, the 802.11 works on 2.4 GHz and 900 MHz. The 2.4GHz still exists today as an ISM band. The 900 MHz, however, in the European Space, doesn't exist anymore. It's used for extending the LTE standards, for the 4G standard today. However, it's still available as an ISM band in the US, in being used by different standards, such as the 802.14.5 WPAN standard for connecting the radio frequency mesh sensors and the smart meters and things like this.

As you can imagine, 802.11 didn't make quite a breakthrough, because at the low data rate it had compared to a wired connection, it was quite low. You can imagine in 1997 you had the 10Base2 and 10Base5 which would already offer 10 Mbps, so ten times the speed but which would be entry-level speed for actually doing data communication.

Now, two years after, so shortly after, we had a revolution. We had a revolution in terms of two different standards that would develop actually at the same time by different places in the

IEEE organization - the 802.11a and b. The 'a' introduce OFDM which was one of the most pioneering types of multiplexing technology, in terms of encoding a lot of quantity of data in the same spatial stream. That took speeds of 254 Mbps. Again theoretical, but impressive even if you divided by two, considering all those mechanisms for reliability and security, you would still get somewhere around 25 to 30 Mbps, which was great in 1999.

However, in terms of frequency band, it was using the 5GHz frequency band. Remember our discussion in a session that we had previously, if you heighten frequency, then you're going to get a lower distance to transmit the signal, and also, a higher cost for the equipment. Well, back in 1999, having a high cost for an entry-level technology really mattered. And having a short distance also mattered, because if your equipment costs a lot, and if you have a short distance to actually propagate wave, then you're going to need a big number of equipment to cover a certain area. It's going to cost you even more money to do that and even a bigger investment. I would say that because at the time during which 802.11a was introduced, it wasn't that popular strictly because of these reasons.

802.11b, even though it had a lower Mbps bandwidth, using the DSSS type of modulation technique, it became really popular. It was actually the one that was branded as WiFi. So, when 802.11b was introduced into the chips in laptops, was branded as WiFi. The reason why it was so popular, was because of the frequency band actually, not the Mbps. Frequency band being 2.4 GHz, it could go up to 100m, even more, so that would be 4 to 5 times better than 802.11a. And because this was an emerging technology that we need to keep it low cost, and also introduce easily into a wide open space. With the big power or penetration for different types of services that the lower frequency band would actually give you, this was hugely popular and this is when, actually, wireless started to become really popular.

Let's tick the clock of time, and move it from 1999 to 2003. 80.2.11g - the old times hero of the 802.11 standards, which really took the standard to the next level for the next six to seven years. This was the best of both worlds. It was a standard that could work on a frequency band of 2.4 GHz with achieving through OFDM a bandwidth of 54 Mbps. Used for a long time and can still be found in a lot of networks. Even though it has been superseded, it was incredibly stable, incredibly worth from an economical, financial perspective, and really invaded all the homes, offices, and coffee shops around the world.

How do the standards compare in area coverage? This is not necessarily important for today's world because you're not going to find 'a' and 'b' anymore. 'G"- you're probably going to find; but not a lot of 'a' and 'b', at least in the consumer space. But it's interesting to look at the fact that the DSSS modulation that was use in 802.11b, actually achieved the highest range in terms of area of coverage. It's also important to understand that while you step away or get farther from the central node, the Access Point in this situation, you don't get just disconnected, but your data rate starts falling and falling and then, at certain point, you get disconnected.

From 2003, it took a relatively long time for our next standard to actually see the light of day. It happened at the end of 2009, 29th of October to be exact. Now, this has far greater speeds -- a theoretical maximum of 600 Mbps. Although this wasn't really achieved in production, this was theoretically maximum. This was guaranteed by the technology, this is by the standard. It has a better coverage in intensity of the signal -- this is important. By the way, it use the internal Digital Signal Processor (DSP) to interpret the signals, it has a much better density over the same coverage as compared to 'g'. If you would look at the 100m coverage, the metric system. The signal you would have at 60m away from the Access Point would be much better in 'n', incomparable to what it would be in 'g', and this was because of the technology that's being used inside the transceiver.

Backwards compatibility was something very important that 'n' was offering. For example, 802.11a - because it was working in 5 GHz, it wasn't backward compatible with 802.11 legacy, and could not work with 802.11b strictly because there were different types of frequencies. However, 'n' can work both in 2.4 and in 5 GHz, so it's backward compatible with all the standards (802.11a/b/g). This is something important to note: whenever 802.11 evolved, it always maintains backward compatibility. This is something really important for the way that wireless technologies are being evolved.

In order to achieve this really high throughput, it uses a special technique. First of all, it uses multiple antennas, multiple radio transceivers in MIMO technology. Not only does it transmit over different channels, but uses different spatial streams in order to transmit data. It also increases the channel width, remember it was 22 MHz when we took the example of 802.11g? It increases the channel width to 40 MHz. That means that by using the same modulation technique, you just have a bigger space in terms of frequency to put data in. And if you make the modulation technique smarter, then, you get even bigger speeds, right ?

Let's look at the two most important technologies that pioneered the standard work. One of them is MIMO comes from Multiple Input Multiple Output. This is just DSP processor to multiplex and de-multiplex the signal. So you take a signal from the wired connection, you split it up into three different spatial streams, and you transmit on all spatial streams at the same time between one AP and another AP. When you get back to the second AP, at the destination, you just de-multiplex, reconstruct the stream and you send it back to the wire or somewhere back to our computer that need it - to an end station that needs it. This immediately tripled the data rate that I had available.

Also, something interesting is Maximum Ratio Combining. In order for you to understand MRC, I have to define something called the "multi-path effect". The "multi-path effect" is the process in which many waves that have the same information are reflected differently from surfaces, and, they have a different signal-to-noise ratio.

You might ask yourself : how come I have many waves with the same information? What do you mean - don't I have the same wave with the same information? Actually, think about an antenna, think about an omni-directional antenna which is the types of antenna that we use in Access Points, and the way that electromagnetic signal works in the air.

It's not a guided signal like you've in the wire. It's more like a circular type of signal - a radial kind of signal that comes out of the omni-directional antenna, and spreads itself within a room. Now, you can think that signal is going to meet your TV, it's going to meet your outer, or your inner wall, and it's going to meet your library, and because all these different surfaces are constructed from different materials, it's going to reflect in a different way; and with the different signal-to-noise ratio. All these reflections, they're going to go to the Wireless Network Interface Card of the computer, and the computer is going to look at all these streams, that by the way, come at different moments in time. In 802.11g, the digital signal processor of the transceiver, we just choose the wave that has the best signal-to-noise ratio. It will say, “this is the best wave clearly, I'm just going to take all the data that I can from that wave and process it.”

Now, what is a problem here? The problem is that although we receive multiple waves, we just going to choose one. Think about it - maybe a different wave, although it has a worse signal-to-noise ratio, maybe it has a chunk of data that better wave that it ends up choosing, didn't happen. This is what MRC's about.

MRC is about implementing in the next DSP (in the destination Access Point DSP), the capability of taking all these waves independent of the signal-to-noise ratio, and independent of the moment that the waves come in. Compose these waves back using a very complex mathematical algorithm, and just make one high quality wave using all the possible information for each reflected wave. Thus, it can increase the throughput, So concluding, MRC's a client-side technology. This means that even if you have a NIC with 802.11n, and you're in a wireless network in which your Access Point is 802.11g, you're still going to have better throughput than 802.11g client , because a 'g' client is only going to select one wave. You're going to make this magical MRC, and you're going to compose the high quality wave. Of course it's impossible to get a higher throughput than the theoretical 54 Mbps, but still you're going to get a better throughput than any 'g' client in that network.

You can think about it from analogy point of view, is like having a cat with multiple ears. So, the cat is going to be able to hear streams coming from multiple directions, all directions, and the cat has multiple ears going to the same brain which is the DSP in this case. It's going be able to understand all this information coming through different sensors.

I've built for you this table that gives you this general comparison of standards. The 'n' and the 'g' are probably the ones you're going to see in a lot of consumer networks. However, the one that it's really, really current and is the one that is pushed by the industry more and more right now, is the 802.11ac. This is the one that we're going to cover in the final nugget that we're going to have.

We've arrived for our final moment, looking at the big star of the show - 802.11ac, or 1 Gbps of bandwidth. This is only the beginning. 802.11ac is currently being complemented to 802.11ad, which promises for the next years in the future, a total possibility of 7 Gbps. That is not only an awesome wireless experience, that is the possibility of making ideas and dreams like smart houses, like being able to be in contact with your loved ones over video streams all the time anywhere, actually possible.

How do we do this, how do we get faster than 802.11n? How do you increase the speed without making it impossibly difficult to actually do it? Well, you've learnt so much in the session, you learn about channels, about modulations, about frequency. It's good to be low or high. You've learn about MIMO, and sending using different antennas to create different streams.

All of these are actually very good ideas. If you have very good ideas, is generally an even better idea to build upon them.

Can we increase the channel width? Right now in 802.11n, it's 40 MHz. Can we increase that? Sure, why not?

Can we increase the number of spatial streams? Right now, we have 4 corresponding to the antennas in 802.11n. Can we go higher? Why not? Just improve the DSP.

Can we improve the modulation? Well, I'm sure that mathematics isn't going to let us down, and QAM64 and is not the best that we can actually do today.

Also, 5 GHz band, what about it? We've been sending in the 2.4 GHz band for a long time now. Why not move up to the 5 GHz band?

Well, thinking about the previous sessions, why didn't we do it? Well, let's think about it. Bigger frequency meant higher equipment costs per frequency, right? But that actually applied in 1999. Right now, like I was saying, the cost of equipment doesn't really go proportional to the raising of the frequency, you can easily raise a frequency without raising the cost at all.

Even the shorter distance at which I can send the signal at 5 GHz, is no longer an issue (paraphrase), because I have improved the power of the signal with the types of DSPs that I have. Remember, from 802.11n that I can get a better signal quality at a specific distance from the AP compared to 'g'? In the 'ac' , I can get a even better signal at the same distance, and if the equipment is not more costly because of the different frequency, then I can just use more equipment to have an even higher, denser and better coverage.

Furthermore, it has advantages compared to 2.4GHz. First of all, it is not as populated. The microwave oven, the headsets, the keyboard, and wireless keyboards, all of these work in 2.4GHz. So, if I move to 5 GHz, I immediately get away from all these kind of different signals that are talking in the same space. It's also bigger space. I can make the channel bigger in the 5 GHz band, because is just more ISM band to use there.

Also, think about a very interesting question. It comes from MIMO. MIMO really solves the nice problem. It said, "Okay, I have three antennas, I can multiplex and communicate with three spatial streams to another three antennas." But think about a LAN topology. If you have an Access Point, with three antennas, and the Network Interface Card that only has one antenna, what's going to happen with MIMO – are you going to talk with one spatial stream, and the other two antennas are just going to sit around doing nothing. Why? You're probably thinking. Because that's the way MIMO was designed - was designed to be a one-to-one communication. If during this antenna to antenna communication, and then the PC comes up and says, "Hey, Access Point, you have two antennas that you're not using, want to talk?" The

Access Point is just going to say, "No, sorry I'm busy with this other guy." This is because that's the way MIMO was built.

So what can we do here? In 802.11ac, MIMO was actually evolved to multiple-user MIMO. In multiple-user MIMO, I get the capability of flexibly using my antennas to a number of 8 different spatial streams with different types of endpoints : with computers; with another AP in order to make a bridge over wireless. That means the two clients can receive signals at the same time on the same frequency, because you're using different spatial streams on the same channel, which means each client has dedicated spatial stream, no collision.

All of the sudden, full duplex becomes possible in wireless; which I don't think it's something that anybody in 1997 was thinking about when developing 802.11.

We have come a very long way and this is just the beginning of what we can do with wireless speed. We can go beyond a gigabit bar. If setting the megahertz channel to 160 MHz, right now, not even the most advanced NIC go to 80 MHz. But if we can do that - 80 MHz for stations, 160 MHz-wide channel for the AP, using 8 spatial streams, we already have the QAM modulation up to 256, which is 8 bits per symbol verses 6 bits that we were using in QAM64, we can get up four times faster just from the modulation, just from the quantity of data we can get in a channel.

We widen the channel four times if we have 8 spatial streams, instead of 4, and we also optimize the usage of the antennas, that's how we can get to 7Gbps, and even more. Whether we have implementation right now, we have for QAM 256 reaching close to 1 Gbps in terms of maximum speed.

This has been a full coverage of the introduction to wireless technologies. As an overview, we have gone through the properties of electromagnetic waves, through frequency and understanding how that works. We have discussed the Carrier Sense Multiple Access \ Collision Avoidance, together with the proper use of channels in wireless LANs; discuss wireless standards, and their evolution impact and focus on the impact of 802.11n with introducing MIMO, and MRC; and ended up with talking about 802.11ac, and how it takes to the next level with multiple user MIMO; and improving on all the innovations that has been created over time.

I hope you have enjoyed the session as much as I have presenting it to you. Good luck with your future professional development, and of course wireless implementations.