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An overview of the IEEE 802.11 standard's evolution

Several lessons were learned as standards makers crafted 802.11a, 802.11b, and 802.11e. That's one of the reasons why 802.11n is so important.

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The wireless toolkit for electronics design engineers widened considerably with the emergence of the 802.11n draft standard. Thanks to its performance benefits, 802.11n will expand the range of wireless connectivity applications and fuel penetration in homes and businesses.

To better understand the politics of 802.11n, it is necessary to first provide some perspective on how the industry got to this point.

The first wireless network standards were approved in late 1999 by the IEEE as part of the 802.11b effort. Those standards featured two major technologies to distribute packets over the radio spectrum using spread spectrum methods that are still in use by most wireless networks.

Shortly after, the 802.11a standard was ratified, which used orthogonal frequency division multiplexing (OFDM) methods to enable higher data rates. Instead of using the same 2.4 GHz frequency band as existing 802.11b products, however, the 802.11a standard operates at in the 5 GHz frequency range. This allows wireless designers to take advantage of a greater number of non-overlapping channels for transmitting data.

With the benefit of hindsight, we can see now that 802.11b's popularity created a powerful legacy ecosystem and established the need for backward compatibility as new wireless protocols emerge.

Lesson 1: Support legacy 802.11b.
The WLAN industry has since learned the importance of supporting legacy 802.11b devices. While it seemed like a good idea at the time to establish a new and potentially higher-performing frequency band at 5 GHz, this incompatibility was ultimately a disadvantage for these products.

While both 802.11a and 802.11b were important efforts, neither could handle the demands of multimedia applications, such as streaming audio and video. Therefore, another effort began to extend these protocols to support higher throughput and lower latencies. That effort turned into the 802.11g standard that was ratified in 2003, which applied the frequency division techniques of 802.11a but used the original 802.11b radio frequencies (see Table 1 below).

Despite lackluster adoption, 802.11a product lines weren't developed for naught. Working on 802.11a taught engineers how to build radios that operate on different frequency bands.

Many multi-frequency products now combine a/b or a/g radios together, and support clients that operate on either frequency. 802.11n products will have multiple-frequency support built-in, so clients can transmit and receive on both the 5 and 2 GHz spectrums simultaneously, boosting bandwidth and throughput and taking advantage of the larger number of channels and more efficient radio transmissions at the higher frequency range.

Lesson 2: Channels matter.
The number of separate transmission channels in the 802.11b/g frequency range is effectively three: channels 1, 6, and 11 are the only ones that don't overlap with the others.

In radio-rich environments, such as a major downtown urban core, there will be plenty of interference from neighboring wireless networks. To help improve throughput, the 802.11n task group is not only using the 5 GHz spectrum to increase the number of channels, but is also considering doubling the size of the channel itself. Thanks to improvements in channel utilization, most 802.11n products are expected to deliver 100-300 Mbps data rates.

With 802.11a and 802.11b, it took several years between the standard ratification and products appearing on retail shelves. The 802.11g effort was the first time that products were introduced in advance of a final standard.

The success of that strategy has influenced how companies have come to market with the 802.11n chipsets in the past year, and one of the reasons there are so many "draft-n" products sold by the major manufacturers.

By developing products in tandem with the evolving specification, many vendors hope to shrink time-to-market for 802.11n products to less than a year. This brings up the next lesson:

Lesson 3: IEEE and Wi-Fi Alliance need to work in parallel.
In the past, engineers in the IEEE working groups developed a draft standard. Once that was finalized, engineers in the Wi-Fi Alliance would start putting together a test and certification plan to ensure interoperability between various implementations of the standard. But as vendors move more quickly and the market becomes more complex, these two groups need to work in parallel.

That is now happening with the 802.11n standards process. The Wi-Fi Alliance agreed last November to start developing 802.11n certification processes in parallel with the IEEE 802.11n working group.

This also helps because the Alliance needs more time to test the implementations submitted from each vendor due to the complexity of the 802.11n standard. Greater inter-organization collaboration may remove issues and differences, such as those that arose with 802.11g: the IEEE made anything over 24 Mbps optional, but Wi-Fi certification required products to support 54 Mbps rates. Speaking of these higher rates, this brings us to the next lesson learned.

Lesson 4: Latency matters.
All of these audio/video applications are placing more importance on latency rather than throughput, which is another

factor driving the draft 802.11n standards efforts that combine improvements on both fronts.

While greater bandwidth is critical, advanced wireless applications will not work acceptably on today's networks without reducing latency times. The difference is important: latency is the total round-trip time that information takes—going from client request to server response and back to the client.

Even the fastest networks suffer from long latencies, which can wreak havoc with audio synchronization, or give users the feeling that "nothing is happening" when they hit the Enter key on their PC browsers. With 802.11n, there is an opportunity to make huge improvements in both latency and bandwidth.

There are several improvements that will help reduce latency. Latency matters most in synchronizing audio applications, particularly with streaming video and with VoIP situations. Delays of a just a few milliseconds can add up over various network router links and result in a mismatched picture to the sound, or turn a phone call with crisp quality into a jumbled mess.

One of the more important is frame aggregation, which groups data packets into larger frames to minimize packet overheard. While throughput is still important, without low latency times, many of these newer applications would not work acceptably on today's networks.

Speaking of the higher data rates supported by 802.11g, here is another lesson. The high end of 802.11g networks sounds very promising, supposedly delivering 54 Mbps data rates. However, what is really going on at these speeds is that there is an almost a 50% overhead that is created to sustain the highest throughput.

Lesson 5: Minimize packet overhead.
Going from 24 to 54 Mbps doesn't buy twice the performance that the raw data rate numbers imply. Any new protocol must do a better job at managing packet overhead than 802.11g, which uses nearly half of its available bandwidth for overhead at the highest data rates.

During 802.11n development, engineers worked hard to reduce overhead and eliminate turnarounds wherever possible. One of the most prolific improvements is frame aggregation.

Instead of sending a single data frame with its overhead, the transmitting client combines and sends a series of frames with a single overhead frame without waiting for each packet to be individually acknowledged.

As a result, an 802.11n client will send more data in a given time period " which makes the transmission more efficient.

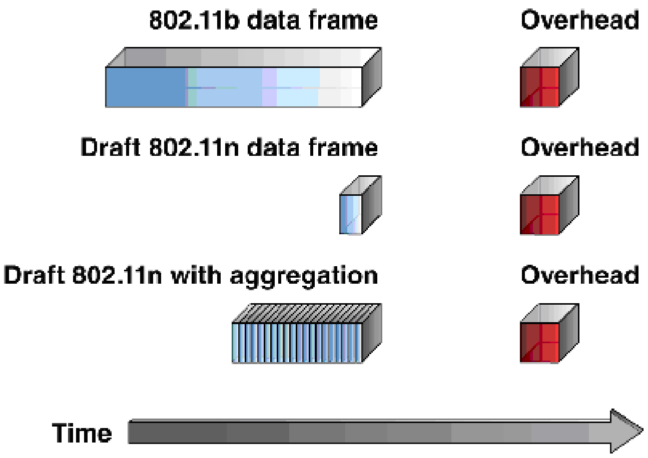

Figure 1: How frame aggregation improves packet efficiencies

Lesson 6: Bring consensus whenever possible.
As the wireless technology impacts a greater number of manufacturers and vendors, relevant working groups get bigger and it becomes more difficult to gain consensus on technical aspects of a standard. By offering an alternate venue for drafting the 802.11n specification, the Enhanced Wireless Consortium (EWC) enabled vendors to put aside their differences and move more quickly towards an agreed-upon standard.

As previously mentioned, the 802.11n specification is much more technically complex than earlier 802.11 standards. One of the byproducts of this complexity is a longer input and approval cycle for new wireless standards. As the membership of various 802.11n working groups had grown, it became harder to achieve consensus.

Late last year, Broadcom and several competitors united stakeholders from competing standards camps to iron-out technical issues and achieve consensus more quickly. This new body, called the Enhanced Wireless Consortium, brought together talented engineers from the major Wi-Fi chip vendors, device manufacturers and PC OEMs to put differences aside and develop a draft specification.

By jump-starting consensus, the EWC laid the groundwork for moving the 802.11n standard towards finalization. The EWC draft was universally accepted by the IEEE 802.11n working group earlier this year, and is on track to be approved early in 2007.

Lesson 7: It isn't only about PCs anymore.
It is clear that PCs aren't the only wireless devices that matter. Any new wireless standard needs to take into account scores of other consumer electronics that will find their way onto home and corporate networks. The 802.11n standard must specifically embrace these devices and support their operation on formerly all-PC networks.

One of the major obstacles for the digital home is putting in new wires to connect everything. Some estimates indicate that Wi-Fi is used to connect devices in half of all homes with broadband connections. This number will continue to climb as the wireless products become more capable. The increasing popularity of wireless networks will spur an increase in the number of applications that will run over these networks.

Indeed, as wireless networks become more pervasive, all of us will see more Wi-Fi enabled printers, music and video devices, cell phones, digital cameras, etc. This new generation of products will enable the wireless transfer of images music and video content that are stored on media servers and media players like Apple's iPod, and Voice over IP telephones.

All of these devices want to share content, applications, and IP addresses wirelessly on the same network. The shear