



Peering into the Alphabet Soup: Relative Advantages of 802.11a, b & g

Abstract

IEEE 802.11 Wireless LAN technology has been a runaway success. However, the continuing evolution of this communications standard has resulted in a great deal of confusion among end customers and even industry insiders. Some advances in the standard, such as 802.11a, 802.11b and 802.11g have opened up new spectrum or resulted in dramatic increases in data rates. This paper briefly describes how the IEEE 802.11 standard has evolved and takes a more detailed look at the relative merits of 802.11b, 802.11a and 802.11g.

Why the Confusion?

The IEEE and equipment manufacturers often get a lot of criticism due to the confusion that inevitably surrounds the development of new networking technologies. At least in the case of the IEEE, this criticism may be a bit misdirected. The IEEE acts a technical standards development body. It makes no pretense at being a marketing organization, nor does it make any attempt to craft consumer-friendly messaging. Instead, the IEEE focuses exclusively on the essential (but often arcane) work of developing standards.

IEEE 802.11 actually has a rather long heritage. The first meeting of the IEEE 802.11 Working Group was held in 1990. The standard itself specifies a radio frequency signaling method and a set of related parameters, collectively referred to as the Physical Layer (PHY). It also describes the behavior of the Medium Access Controller (MAC), which determines when each radio in a given network can transmit without interfering with other users.

Completing the original IEEE 802.11 Standard took seven years (NOTE: Blinking or rubbing your eyes won't help...this is not a misprint). When it was finalized in 1997, it described the MAC much as it exists today. The original PHY, however, only supported data rates up to 2 Mbps in the 2.4 GHz band. While this was perfectly adequate for some applications, it immediately became clear that higher data rates were absolutely essential before 802.11 could enjoy wide market adoption.

Two new Task Groups were formed to develop extensions to the 802.11 Standard. Task Groups are simply designated with letters of the alphabet (TGa, TGb, etc.) in the order in which they are formed. Thus began the "alphabet soup" syndrome that characterizes WLAN technology to this day. The first Task Group formed was Task Group A, which was chartered with establishing a standard to support higher data rates in the then newly opened 5 GHz band. The work of this Task Group eventually resulted in the 802.11a extension to the original standard.

As you may have guessed by now, the next group formed was Task Group B, whose efforts eventually resulted in IEEE 802.11b. This group was chartered with developing higher data rates in the 2.4 GHz band while supporting backward compatibility with equipment conforming to the original 802.11 Standard. The result was wildly successful. IEEE 802.11b has been widely adopted and lead to the establishment of the Wi-Fi Alliance which tests equipment from literally hundreds of vendors to ensure interoperability.

To date, no less than *eleven Task Groups have been formed* to provide a variety of enhancements to the original IEEE 802.11 Standard. Task Groups will continue to be formed whenever essential enhancements to the Standard are identified. The work of these groups is vital to the continuous development and improvement of WLAN technology. That said, so much activity has also caused a lot of confusion and earned the dubious title of “alphabet soup”. Table 1 summarizes the activity of all past and present IEEE 802.11 Task Groups.

Group	Activity	Status
Original 802.11 Standard	Developed MAC & PHY for WLAN. Supported 1 & 2 Mbps data rates in 2.4 GHz band.	Completed in 1997 (IEEE 802.11)
TGa	<i>PHY extension for 5 GHz bands. Supports more channels (up to 12 non-overlapping) and higher data rates (up to 54 Mbps)</i>	<i>Completed in 1999 (IEEE 802.11a)</i>
TGb	<i>PHY extension for 2.4 GHz band. Data rates increased to 11 Mbps & backward compatible with original 802.11 Standard</i>	<i>Completed in 1999 (IEEE 802.11b)</i>
TGc	Supplement to 802.1d to support 802.11 frames	Completed in 2000
TGd	Regulatory Domain Update – Adds capability for 802.11 radios to dynamically adapt to different regulatory domains	Completed in 2000
TGe	MAC level enhancement for Quality-of-Service (QoS)	Ongoing. Est'd completion 2H '03
TGf	Recommended practices for Inter Access Point Protocol	Ongoing. Est'd completion in 2H '03
TGg	<i>PHY extension for 2.4 GHz band. Increases peak data rates to 54 Mbps and preserves backward compatibility with 802.11b</i>	<i>Ongoing. Est'd completion 1H '03</i>
TGh	PHY extension to include Dynamic Frequency Selection and Transmit Power Control for compliance with European regulatory requirements for 5 GHz bands	Ongoing. Est'd completion 1H '03
TGi	Enhanced security measures (encryption, authentication, and key management)	Ongoing. Est'd completion 2H '03
TGj	PHY extension to provide channelization to encompass Japanese allocations from 4.9 to 5.1 GHz	Ongoing. Est'd completion 2H '04
TGk	Radio resource management	Ongoing. Est'd completion 1H '05

Table 1 - Summary of IEEE 802.11 Standards Activity

Faster is Better

In the networking business, there is no doubt that speed sells. For this reason, Task Groups devoted to increasing data rates have both controversial and highly visible. TGA, TGB and TGG have each developed standards for higher data rates. Vendors continue to hold a public debate on the relative merits of each of these rate extensions to the 802.11 Standard. The following paragraphs describe Intersil's perspective on each of these rate extensions in more detail.

In the Beginning: IEEE 802.11b

In reality, IEEE 802.11a and 802.11b were developed in parallel over the same period of time. IEEE 802.11b is addressed first for two reasons:

1. Products conforming to 802.11b hit the market two years before 802.11a product
2. 802.11b has been tremendously successful. Of the more than 40 million 802.11 devices in service world wide, over 95% are 802.11b. It therefore forms the bedrock of the WLAN market.

In terms of technical specifics, 802.11b uses a waveform referred to as Complimentary Code Keying (CCK). The waveform in the original 802.11 was Direct Sequence Spread Spectrum (DSSS). CCK uses the same single carrier waveform as the original 802.11 specification (Quadrature Phase Shift Keying, or QPSK) and utilizes the same 2.4 GHz spectrum. It achieves higher rates by means of a different coding method.

Coding refers to the manner in which digital information is processed to enhance system reliability as the data is transmitted wirelessly. There are many ways in which coding is implemented, and some methods are more efficient than others in terms of data throughput. In terms of coding efficiency, CCK is far more efficient than the original DSSS waveform. CCK is therefore capable of peak rates of 11 Mbps as compared to only 2 Mbps for DSSS.

The advantages of 802.11b are substantial:

1. IEEE 802.11b has excellent range and can match 10baseT wired Ethernet speeds (supporting data rates of 1, 2, 5.5 and 11 Mbps)
2. It is fully backward compatible with the original 802.11 Standard
3. 2.4 GHz spectrum is available on essentially a worldwide basis.
4. 802.11b technology is becoming fairly mature and prices are declining. Thus, 802.11b is the most cost effective of the three PHY variants discussed.

The ability to match 10baseT data rates proved to be a watershed event. IEEE 802.11b products were first launched in 1999. The response from customers was immediate and positive. The Wi-Fi Alliance was formed during this period to provide certified testing for interoperability among products from multiple vendors and promotion of the standard. By late 2000 the market had expanded from <1M units annually to more than 4 M units per year. Today, IEEE 802.11b still accounts for more than 90% of WLAN sales.

Disappointment: IEEE 802.11a

As mentioned above, 802.11a was developed over the same period of time as 802.11b. On the surface, 802.11a has a lot of advantages. However, as we shall see, some underlying weaknesses have prevented this technology from rivaling the success of 802.11b, let alone displacing it as some of its proponents had predicted.

IEEE 802.11a operates in the 5 GHz bands. In the U.S., there is a total of 300 MHz of allocated spectrum in the 5 GHz band available for use by 802.11a equipment. This translates into twelve non-overlapping channels as compared to only three for 802.11b systems operating in the 2.4 GHz band. In addition, 802.11a uses Orthogonal Frequency Division Multiplexing (OFDM) as the modulation scheme. OFDM offers excellent performance for indoor WLAN applications and supports data rates up to 54 Mbps.

With up to twelve non-overlapping channels and maximum data rates of 54 Mbps, it would appear that 802.11a enjoys an absolutely insurmountable advantage relative to 802.11b. However, events have proved otherwise. In reality, market adoption of 802.11a has been a major disappointment. At present, 802.11a accounts for not more than 5% of WLAN sales. Further, the technology does not appear to be gathering significant momentum.

Due to the complexity of the waveform and the higher operating frequency, it took much longer to ready 802.11a technology for market. The first volume shipments occurred in late 2001 --- more than two years after the first 802.11b equipment arrived on store shelves. In those vital two years, 802.11b became a very popular and widespread technology. Thus, 802.11a ran into an entrenched incumbent in the market.

In reality, 802.11a suffers from three major drawbacks:

1. It is not backward compatible with 802.11b. 802.11a uses a different waveform and operates at a different frequency.
2. The spectrum in the 5 GHz bands is not harmonized on a worldwide basis. There are significant differences in spectrum allocation and technical requirements between the US, Europe, and Asia. It is therefore difficult for manufacturers to get a single product authorized for use in all three major regulatory domains.
3. Equipment operating at 5 GHz generally provides much lower range than equipment operating at 2.4 GHz. All things being equal, signals propagate better at lower frequencies. This effect can be largely overcome by using higher output RF power amplifiers. This results in much higher power consumption. While possibly acceptable in Access Points (APs), this approach is impractical for mobile devices.
- 4.

Although 802.11a has been a disappointment to date, there are reasons for optimism in the longer term. Regulatory issues that have daunted 802.11a are being overcome and manufacturers are finding the means to build devices that can span all of the 5 GHz bands (from 4.9 GHz to 5.925 GHz) used on a worldwide basis.

Of all of the issues facing 802.11a technology, the matter of range is possibly the most serious. As mentioned above, this can be overcome by using bigger power amplifiers (PAs) that put out 100 – 200 mW. Due to the relative inefficiency of OFDM amplifiers, these types of power amplifiers can consume 1 – 2W of power alone excluding the rest of the radio. For devices plugged into prime power, this is not a problem. However, for mobile clients the power drain is unacceptable. Still, it is argued, in some high-density applications, short range may not be a serious drawback. Range may not be a major problem in the enterprise because more APs can be installed. However, in the home, a single AP must be able to cover the entire home or apartment. Given that the consumer space is both larger and growing faster than the enterprise market, lack of range has been a serious inhibitor for 802.11a equipment as a stand-alone or replacement technology for 802.11b.

Faster & Further: IEEE 802.11g

By mid 2000, it became clear that 802.11b was beginning to gather serious market momentum. At the same time, it was becoming equally clear that the 11 Mbps peak data rate was inadequate for many applications. Task Group G (TGg) was formed within IEEE 802.11 to come up with the means of increasing data rates within the 2.4 GHz band. A key technical requirement levied on TGg was that the resulting standard be made to provide for backward compatibility with existing 802.11b equipment.

The work of TGg is now nearing completion (expected by mid 2003). Several proposals were put forward for the group to consider. In the end, Intersil's OFDM-based proposal was selected as the basis for the new standard. Use of OFDM was extremely appealing to the Task Group because many companies had already developed OFDM capability for 802.11a equipment. As it became increasingly clear that the 802.11a market was struggling, 802.11g offered a new opportunity to deploy this powerful technology. Further, by using the same OFDM waveform as already being used in the 5 GHz bands, design of dual band devices is much simpler than it would otherwise have been had a new waveform been selected.

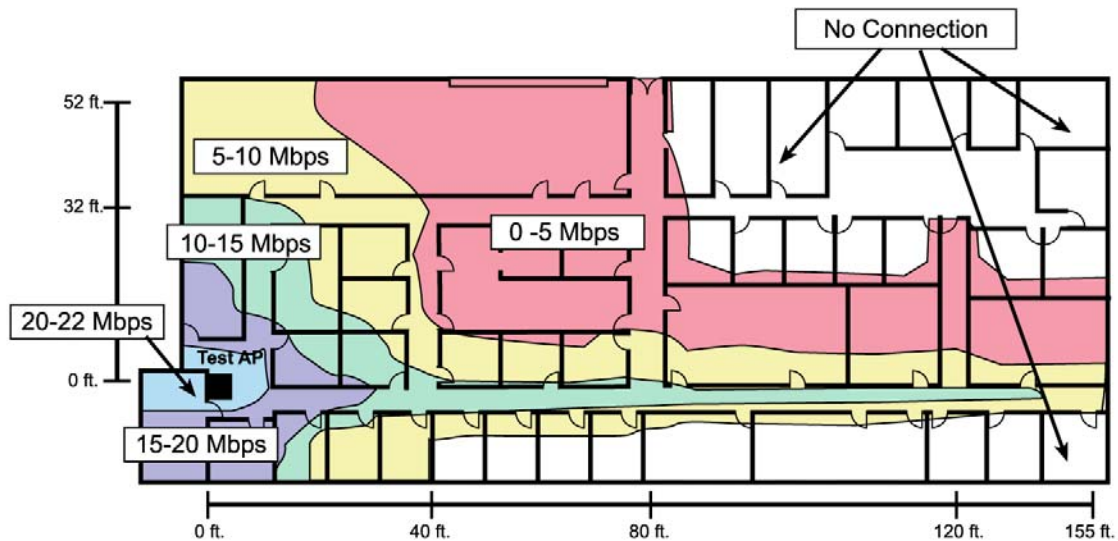


Figure 1 - 802.11a Does Not Provide Good Range in Typical Indoor Applications

On several levels, 802.11g offers the best of two worlds. It can match the peak 54 Mbps data rates of 802.11a. At the same time, it has much better range than 802.11a due to the fact that it operates at a lower carrier frequency (2.4 GHz as compared to 5.3 GHz). For similar data rates and transmit power, 802.11g provides roughly twice the reach of an 802.11a system.

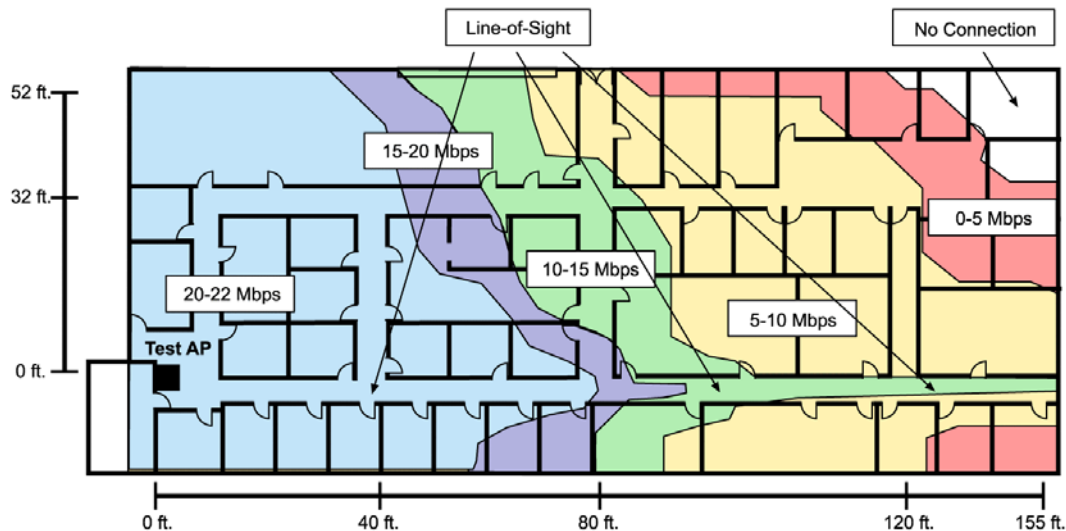


Figure 2 - 802.11g Matches 54 Mbps Peak Rate of 802.11a and Provides Much Better Range Indoors

Figures 1 and 2 show a comparison of range for 802.11a and 802.11g equipment in the same indoor environment. The location is an office building. The offices shown have doors and floor-to-ceiling walls (rather than cubicles). Walls are drywall over studs. This environment is also fairly typical for home applications. As it turns out, 5 GHz signals cannot penetrate walls as well as signals at 2.4 GHz. This effect is clearly demonstrated in Figure 1. Note that 802.11a is only able to provide long reach down a long corridor where line-of-sight propagation is possible. In contrast, Figure 2 shows that 802.11g radios operating at the same transmitted power provide more than twice the overall range of 802.11a equipment.

Although the 802.11g Standard will not be completed until the middle of 2003, customer demand is very strong. *The compelling advantages of 802.11g are:*

- 1.) Matched 802.11a peak data rates of 54 Mbps
- 2.) Fully backward compatible with 802.11b
- 3.) Provides roughly twice the indoor range of 802.11a equipment under same conditions simulating home and office use
- 4.) 2.4 GHz spectrum is available on a worldwide basis.
- 5.) Uses same OFDM waveform as 802.11a, thus facilitating design of dual band equipment

It is becoming increasingly clear that 802.11g will displace 802.11b as the mainstay of WLAN sales much sooner than originally thought. Until recently, conventional wisdom held that 802.11b would be the dominant WLAN technology in terms of unit volume through 2004. Currently, however, it appears that 802.11g will become the volume leader by the second half of 2003.

In Summary...

Current 802.11 WLAN products represent over a decade of investment and product development. Table 2 presents the relative advantages of each of the major radio variants.

<i>PHY</i>	<i>Max Data Rate (Mbps)</i>	<i>Range</i>	<i># Non-overlapping channels</i>	<i>Backward compatible with 802.11b</i>
802.11a	54	Poor	12	No
802.11b	11	Good	3	---
802.11g	54	Good	3	Yes
Dual Band 802.11a/b/g	54	Good	15 (US)	Yes

Table 2 Top Level Summary of 802.11a, b, & g

The evolution of WLAN technology is an on-going process. IEEE 802.11g represents the current state-of-the-art, but it is by no means the end of the line. In the home environment, it is essential that a single AP provide coverage of the entire home. The range advantage should make 802.11g the dominant platform in the retail space.

In the enterprise, the picture is not quite as clear. In enterprise settings, the range issue associated with 5 GHz can be overcome by means of installing more Access Points. In this space, the higher number of channels available in the 5 GHz band makes 802.11a more attractive because a higher user density can be supported. But remember, 802.11g was designed specifically to facilitate design of cost effective dual band radios. The next major step in WLAN evolution is therefore expected to be the emergence of dual band radios. Table 2 clearly shows that dual band radios will offer an extremely attractive combination of product attributes. We should start seeing dual band devices capable of operating in both the 2.4 and 5 GHz bands on a worldwide basis in the next 12 months.