WHITE PAPER

IEEE 802.11g

The Next Mainstream Wireless LAN Standard

Today's popular IEEE 802.11b (802.11b) for wireless local area networks (WLANs) has changed the face of networking, providing tremendous flexibility for mobile workers and hassle-free Internet sharing for home users. The next milestone in the evolution of WLANs is the introduction of IEEE 802.11g (802.11g). This new IEEE standard will dramatically improve the performance of WLANs, while providing compatibility with the existing installed base of 802.11b networks. The purpose of this white paper is to:

- Provide an explanation of existing WLAN standards
- Describe 802.11g specification requirements
- Set expectations for 802.11g performance
- Discuss 54g™, an implementation of the draft 802.11g specification that is available today

WLAN Market

The WLAN market has grown rapidly as wireless technology has evolved to meet fundamental needs of businesses and technology consumers alike:

- Corporate IT departments deploy WLANs to support roving employees, reduce the cost of cabling and recabling the physical plant, and provide a rapid response to changes in demand.
- The mobile worker uses public access WLANs in cafes, airports, trains, lobbies, and remote corporate sites to connect to the corporate network or Internet.
- Small offices and enterprises use WLANs to share Internet connections, printers and peripherals, and create backup connectivity solutions while remaining highly scalable and flexible, without the costs of cabling.
- The home customer uses a WLAN to share a broadband Internet connection among multiple family PCs without drilling holes and installing cable throughout the home.

These customers have adopted WLAN solutions to achieve flexibility, connectivity, mobility, and low-cost deployments not available through conventional wired solutions. The numbers speak for themselves—over 35 million WLAN nodes have already shipped and the number of nodes is expected to grow to 100 million in 2005.

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WLAN STANDARDS

The foundation of mainstream WLAN products began with the original 802.11 standard developed in 1997 by the Institute of Electrical and Electronics Engineers (IEEE). That base standard continues to be enhanced through document additions that are designated by a letter following the 802.11 name, such as 802.11b, 802.11a, or 802.11g. The letter suffix represents the task group that defines the extension to the standard. These enhancements bring increases in data rate and functionality leading to rapid progression of the WLAN market. The following table briefly summarizes the enhancements related to data rate (the WLAN physical layer). More information is available at http://grouper.ieee.org/groups/802/11/.

Table 1: IEEE 802.11 Specifications

	802.11b	***802.11a***	***802.11g***
Standard approved	July 1999	July 1999	Pending, expected June 2003
Maximum data rate	11 Mbps	54 Mbps	54 Mbps
Modulation	CCK	OFDM	OFDM and CCK
Data rates	1, 2, 5.5, 11 Mbps	6, 9, 12, 18, 24, 36, 48, 54 Mbps	CCK: 1, 2, 5.5, 11 OFDM: 6, 9, 12, 18, 24, 36, 48, 54 Mbps
Frequencies	2.4–2.497 GHz	5.15–5.35 GHz 5.425–5.675 GHz 5.725–5.875 GHz	2.4–2.497 GHz

IEEE 802.11b

Ratified by the IEEE in July 1999, 802.11b extends the original IEEE 802.11 direct sequence spread spectrum (DSSS) standard to operate up to 11 Mbps in the 2.4-GHz unlicensed spectrum using complementary code keying (CCK) modulation. The four data rates of 1, 2, 5.5, and 11 Mbps are specified on up to three non-overlapping channels, and the lowest two rates are also allowed on up to 13 overlapping channels.

IEEE 802.11a

Ratified by the IEEE at the same time as 802.11b, 802.11a (802.11a) operates in the 5-GHz spectrum. The 802.11a standard was designed for higher bandwidth applications than 802.11b, and includes data rates 6, 9, 12, 18, 24, 36, 48, 54 Mbps using orthogonal frequency division multiplexing (OFDM) modulation on up to 12 discrete channels.

IEEE 802.11g

In July 1999, the 802.11g subcommittee was tasked to extend the 2.4-GHz unlicensed spectrum to data rates faster than 20 Mbps. The resulting 802.11g draft specification provides optional data rates of up to 54 Mbps, and requires backwards compatibility with 802.11b devices to protect the substantial investments in today's WLAN installations.

The 802.11g draft specification includes mandatory and optional components. It specifies OFDM (the same technology used in 802.11a) and CCK as the mandatory modulation schemes with 24 Mbps as the maximum mandatory data rate, but it also provides for optional higher data rates of 36, 48, and 54 Mbps.

The 802.11g draft specification is nearly complete, and the IEEE is in the final stages of ratifying it. Only minor revisions will likely be made to the standard before its projected ratification in June 2003. Products based on the 802.11g draft specification are available today.

MARKET ACCEPTANCE OF WLAN STANDARDS

802.11b

The industry standard for WLANs is 802.11b. Products based on 802.11b have gained mainstream acceptance as the first wireless networking products with acceptable speeds, affordable prices, and universal compatibility as certified by the Wi-Fi Alliance. More than 98% of today's WLAN infrastructure includes 802.11b products.

802.11a

The first 802.11a based products became available late 2001. These products provide data rates up to 54 Mbps in the 5-GHz frequency band. Even though the technology delivers greater data rates, it has had limited market acceptance. This has been due primarily to its lack of backward compatibility with 802.11b based products, shorter connectivity range, and higher deployment costs.

802.11g

The next mainstream wireless LAN standard will be 802.11g. This technology satisfies the bandwidth needs of the market globally and economically, while remaining compatible with the installed base of mainstream products.

802.11g Approval and Certification Timeline

The IEEE met in January 2003 to initiate the sponsor ballot process. A sponsor ballot re-circulation is then expected to occur March through May 2003. During this time, significant changes to the draft specification are highly unlikely. The official sign-off of the 802.11g specification as a standard is expected by June 2003.

The IEEE standards body does not validate interoperability or compliance with the standard, the industry association Wi-Fi Alliance performs these tasks. The Wi-Fi Alliance has already begun to build a testing program to certify 802.11g interoperability based on the current draft. The Wi-Fi certification for 802.11g products is expected to be available shortly after the standard is signed off. This follows the Wi-Fi Alliance's successful 802.11b and 802.11a certification programs.

The 802.11g draft specification products are available today. If changes to the specification occur, vendors expect to update products with a simple software revision.

802.11g PERFORMANCE AND CHARACTERISTICS

Data rate, range, throughput, and compatibility vary among the three WLAN standards. These variations are caused by differences in frequency, modulation schemes, and number of data rates.

802.11g DATA RATES

The 802.11 standard technologies all support multiple data rates to allow clients to communicate at the best possible speed. Data rate selection is a tradeoff between obtaining the highest possible data rate while trying to minimize the number of communication errors. Whenever there is an error in the data, the systems must spend time to retransmit the data until it is error free. Each 802.11 client performs a procedure to select the best data rate. The 802.11g clients can select from the widest possible range of both OFDM data rates of 54, 48, 36, 24, 18, 12, 9, and 6 Mbps, and the CCK rates of 11, 5.5, 2, and 1 Mbps.

802.11g Range and Data Rate

As distance from the access point increases, 802.11 based products provide reduced data rates to maintain connectivity. The 802.11g draft specification has the same propagation characteristic as 802.11b, because it transmits in the identical 2.4-GHz frequency band. Because 802.11b and 802.11g products share the same propagation characteristics, implementations provide roughly the same maximum range at the same data rate. Because 5-GHz radio signals do not propagate as well as 2.4-GHz radio signals, the 802.11a product range is limited compared to the 802.11b or 802.11g product range.

The following figure illustrates the expected data rate of each technology at different ranges.

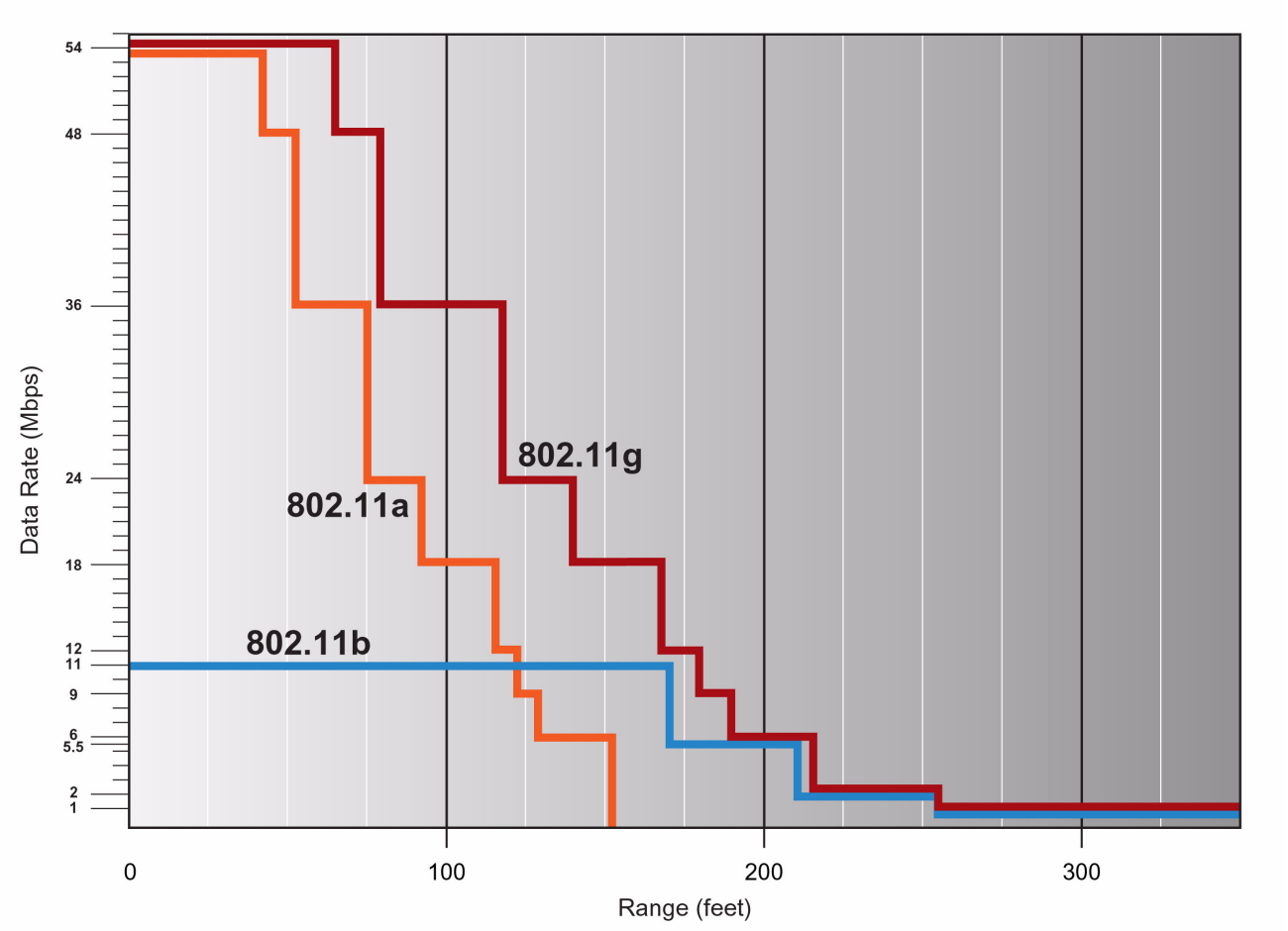

Figure 2: Expected 802.11a, 802.11b, and 802.11g Data Rates at Varying Distance from Access Point

Typically, 2.4-GHz 802.11g networks have the same coverage as 2.4-GHz 802.11b networks. The 802.11b standard uses CCK modulation, while 802.11g uses both CCK modulation for backward compatibility and OFDM modulation to achieve better throughput at a given distance. The 802.11a standard also uses OFDM modulation, but there is more signal loss as it travels through objects because it uses a higher frequency.

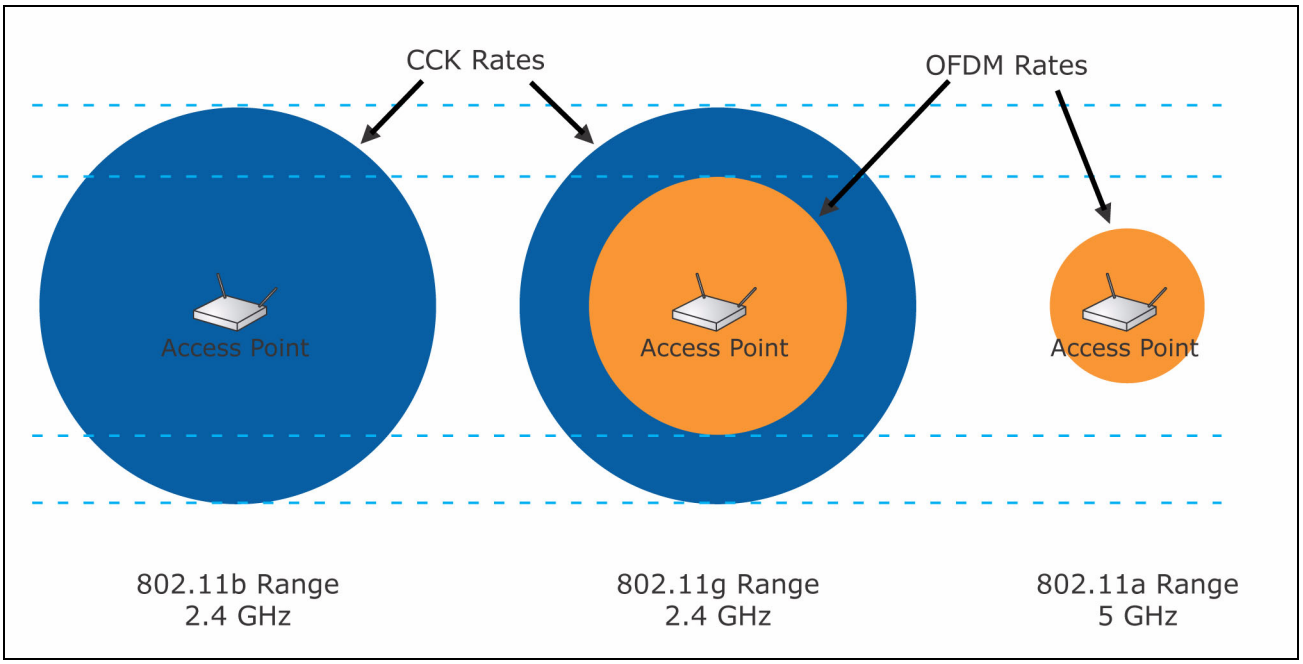

Figure 3: Relative Range of 802.11b, 802.11g, and 802.11a Devices

802.11g THROUGHPUT

Throughput is not the same as data rate for networking systems, because of overhead, environment, and network composition. The throughput of 802.11g products can depend on whether there are 802.11b products nearby. Performance is best in environments where an 802.11g access point (AP) is only communicating with 802.11g clients in a homogeneous WLAN. In these environments, the data rate within 75 feet is 54 Mbps and the throughput is 22–24 Mbps when using Transmission Control Protocol (TCP).

In the interest of maximizing performance in the presence of 802.11b products, the 802.11g draft specification provides 802.11g APs the option to coordinate the use of the transmission medium with *protection* mechanisms (see sidebar). Because the protection mechanisms require overhead communication, compatibility is provided at the expense of throughput. The request to send/clear to send (RTS/CTS) protection mechanism lowers the maximum throughput to approximately 12 Mbps, as shown in the following table.

Table 2: Expected Maximum Throughput for IEEE 802.11 Environments

Distance (Feet)	*802.11b (Mbps)*	*802.11a (Mbps)*	*802.11g-only (Mbps)*	*802.11g Mixed Environment with RTS/CTS (Mbps)*
10	5.8	24.7	24.7	11.8
50	5.8	19.8	24.7	11.8
100	5.8	12.4	19.8	10.6
150	5.8	4.9	12.4	8.0
200	3.7	0	4.9	4.1
250	1.6	0	1.6	1.6
300	0.9	0	0.9	0.9

The use of a protection mechanism is optional in the 802.11g draft specification, and it is possible to exceed the performance in the final column of Table 2 using no protection mechanism.

802.11g COMPATIBILITY

Because 802.11g uses identical radio signaling (CCK) at the lower four data rates, it is fully backward compatible with 802.11b. This enables networks to continue supporting 802.11b enabled devices when migrating to the higher performance standard.

Air Traffic Control

The 802.11g draft specification allows for optional protection mechanisms for use in a mixed 802.11b/g environment mode. This provides for managed communication in the presence of 802.11b clients, and prevents 802.11b clients from improperly assessing that the airspace is empty in mixed environments. When the airspace is busy, 802.11g OFDM signals may not be heard by 802.11b radios. While 802.11g products still communicate at the same 802.11g data rates, the protection mechanism causes signaling overhead and results in reduced throughput to the user.

Client

The 802.11g draft specification allows 802.11g clients to use one of several protection mechanisms in the mixed 802.11b/g environment mode. The AP can direct clients to use protection through an optional signaling mechanism specified within the 802.11g draft specification. The RTS/CTS protection mechanism is one method that prevents multiple radios from broadcasting simultaneously when using different modulation. The RTS protection is analogous to a pilot's take off request to an air traffic control tower—the pilot is not allowed to use the airspace until verifying with the control tower that the airspace is clear. The CTS protection is like the clearance from the tower.

A protection mechanism that has less throughput degradation than RTS/CTS is CTS only. With a maximum TCP throughput of 14.5 Mbps, this protection is less robust when some clients cannot receive from each other. With any of the protection mechanisms, 802.11g throughput is still greater than or equal to 802.11b throughput at the same distance.

AP

Some 802.11g APs allow the user to choose whether to invoke the protection mechanism. Enterprise-class 802.11g APs may allow users to tune the protection mechanism algorithm to optimize network system performance.

NETWORK ENVIRONMENT CONSIDERATIONS

One of the major benefits of the 802.11g draft specification is the mandate for 802.11g and 802.11b devices to communicate with each other. At all 802.11b rates, 802.11b devices communicate with 802.11g products as if they were 802.11b products. As previously discussed, 802.11g products behave differently at higher data rates if there are 802.11b devices in the network environment. Understanding this behavior is important in setting performance expectations given the large installed base of 802.11b clients and the planning of network capacity until 802.11b clients are replaced with 802.11g (the presence of an 802.11a 5-GHz network has no effect on these scenarios). The following scenarios show how the type of network environment is determined both by the network infrastructure and client devices.

802.11b-Only Legacy Environment

When the AP and all clients are 802.11b, communication occurs at 802.11b data rates. Overhead communication between the products effectively limits the maximum throughput to 5.8 Mbps. When the products are communicating at greater distances and lower data rates, the throughput is correspondingly reduced.

802.11g-Only

When the AP and all clients are 802.11g, communication occurs at the highest possible TCP throughput. The 802.11g AP detects that all of the clients are 802.11g and instructs the network not to use any protection method. Without a protection mechanism engaged, throughput of 24 Mbps or greater is possible.

802.11g AP, Mixed Clients

When the AP is 802.11g and there is a mixture of 802.11g clients and 802.11b clients, the AP senses both technologies on the network. The 802.11g AP may instruct 802.11g clients to use a protection mechanism (RTS/CTS). Effectively, 802.11g clients function at reduced 802.11g TCP throughput (up to 12 Mbps), which is faster than the 802.11b client that communicates at maximum throughput of up to 5.8 Mbps.

802.11b AP, 802.11g Client

When the AP is 802.11b and the client is 802.11g, the 802.11g client is able to successfully associate and communicate with the 802.11b AP. Communication between the AP and the 802.11g client uses CCK modulation and achieves typical 802.11b speeds. An 802.11g client can always function as an 802.11b client.

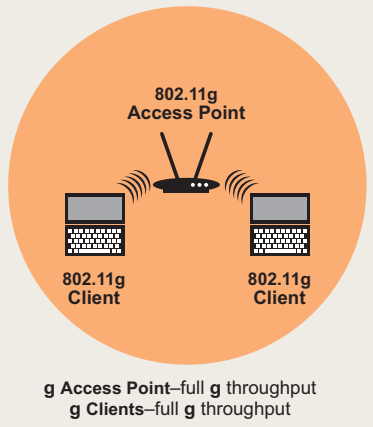

Figure 4: 802.11g-Only Environment

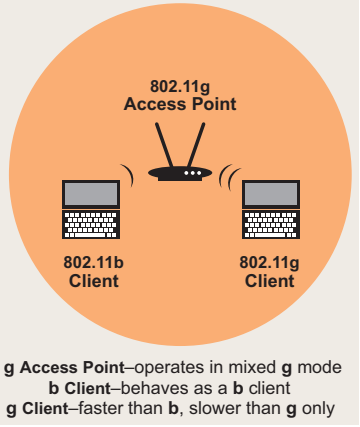

Figure 5: 802.11g AP, Mixed Client Environment

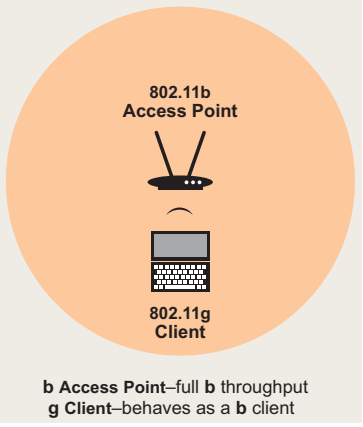

Figure 6: 802.11b AP, 802.11g Client Environment

Multiple 802.11g APs, Mixed Clients

When there are multiple 802.11g APs and a single 802.11b client on the same channel, all 802.11g APs may signal the use of the protection mechanism (RTS/CTS). Effectively, 802.11g clients function at a reduced 802.11g TCP throughput (up to 12 Mbps), which is faster than the 802.11b client, which communicates at a typical 802.11b TCP throughput (up to 5.8 Mbps).

The APs can also be configured to use different channels for their 802.11g clients so that the 802.11g-only networks do not need to use a protection mechanism. This allows 802.11g clients to have full TCP throughput as if they were in an 802.11g-only network.

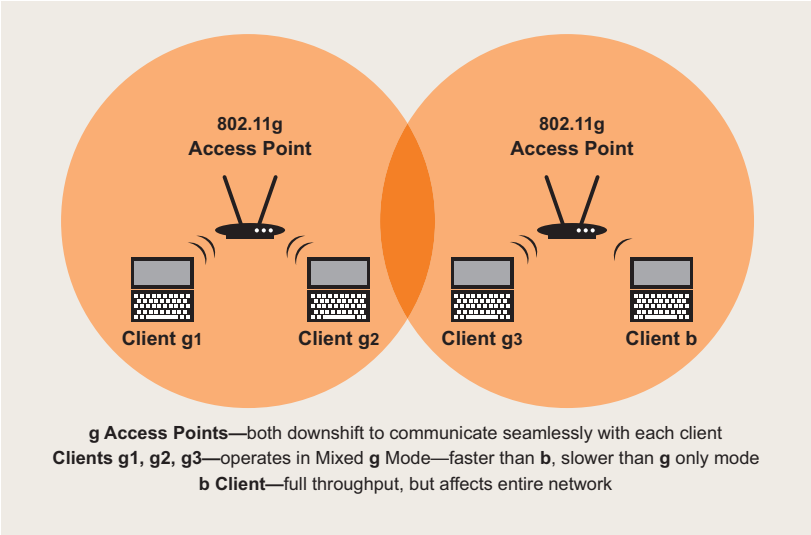

Figure 7: Multiple 802.11g APs, Mixed Clients

WHICH STANDARD SHOULD I DEPLOY?

With any network technology, there are tradeoffs between performance and cost. With wireless technologies, other factors such as range and capacity should also be considered. Table 3 summarizes typical user requirements and the characteristics of WLAN technology. In most cases, 802.11g provides the correct mix of characteristics for the different categories of user requirements. Upgrading to 802.11g is the easiest and least expensive choice, because it can be done gradually, without sacrificing the current WLAN infrastructure. The 802.11g APs automatically support existing 802.11b clients while providing increased speed to 802.11g clients.

Planning Network Migration

As network managers plan upgrades from existing wireless 802.11b networks, the two basic technologies to consider are 802.11g and 802.11a/g. An upgrade to 802.11g is a simple proposition. Users equipped with 802.11g enabled notebooks will gain immediate access to the 802.11b network. These users will experience a throughput boost as APs are upgraded to 802.11g. As budget allows, dual-band 802.11a/g products can be deployed to meet the demand for more network capacity while remaining backward compatible.

The dual-band APs may need to be more closely spaced to ensure coverage for 802.11a clients. Transmit power control can be enabled in the 802.11g network to optimize performance of closely spaced access points. Because 802.11g is forecast to rapidly replace 802.11b, a dual-band a/b AP solution becomes immediately obsolete.

Table 3: WLAN User Requirements and Technology Characteristics in the U.S.

Typical WLAN User Requirements					
Type of WLAN	***Peak Speed***	***Capacity***	***Range***	***802.11b Compatible***	***Budget***
Enterprise	High	Variable	Variable	Yes	High
Public Access	Low	Medium	High	Yes	Medium
Small Business	Medium	Medium	High	Yes	Low
Home	Medium	Low	High	Yes	Low

WLAN Technology Characteristics					
WLAN Technology	***Peak Speed***	***Capacity***	***Range***	***802.11b Compatible***	***Cost***
802.11b	Medium	Low	High	Yes	Low
802.11a	High	High	Low	No	Medium
802.11g	High	Medium	High	Yes	Low
802.11a/g	High	High	High	Yes	High

ENTERPRISE

Enterprise WLANs are typically an overlay to a wired infrastructure serving the needs of mobile workers for e-mail, web browsing, and intranet access when they are away from their desks. Coverage is typically more important than connection rate. Enterprises can benefit from the higher bandwidth and backward compatibility of 802.11g networks today, and can outfit densely populated environments or plan for wired network replacement with dual-band 802.11a/g networks. It is expected that enterprise customers will future-proof their networks by providing 802.11g connections on the client side, and upgrade infrastructure as budget permits.

PUBLIC ACCESS—HOTSPOTS

Compatibility and range matter most to Hotspot operators and public access WLAN customers. Public WLAN Hotspots must be certain that their APs can communicate using mainstream standards that offer connectivity to the widest possible range of subscribers. Today, nearly all Hotspot traffic is 802.11b. Public access operators remain in the 2.4-GHz band because it offers twice the range and four times the coverage area of the 5-GHz alternative, and public access customers continue to use the 2.4-GHz spectrum to maximize connectivity. As Hotspots upgrade, they will add 802.11g to their networks to add range and preserve interoperability.

SMALL BUSINESS

A small business WLAN needs to cover small to medium-sized areas and support a variety of applications, such as e-mail, web browsing, and large file transfer. Because of good performance characteristics, costs, and range, 802.11g again makes the most sense. The 802.11g draft specification offers compelling value by minimizing the number of APs, lowering deployment costs, while future proofing the installation with a mainstream standard. Many small businesses may simply require a single 802.11g AP and no wired infrastructure at all.

HOME

Many homeowners today have multiple computers and want to share a common Internet connection. For these uses, low-cost 802.11g or 802.11b solutions suffice. As the number of home network devices expand and bandwidth-hungry applications grow (such as gaming, home-wide audio and video streaming, and home security), an 802.11g WLAN provides up to five times the performance of an 802.11b WLAN. The draft 802.11g solutions provide the bandwidth for added devices and new applications, with a range that covers most homes with one or two APs.

WHAT IS 54g™?

54g™ is the maximum performance implementation of the IEEE 802.11g draft specification. Compliant with the latest version of that document, 54g™ technology provides up to 54-Mbps connectivity with the highest throughput allowed by the specification and provides the industry's best range and latest security. The 54g™ logo can be found only on products that achieve this high level of performance (see Figure 8).

54g™—MAXIMUM PERFORMANCE 802.11g

The 54g™ implementation is designed to exceed the requirements of the IEEE 802.11g draft specification, as shown in Table 4. The 54 Mbps data rate and short slot turnaround time are optional in the draft specification but are included in 54g™. These features more than double the expected throughput of a product that just meets the draft specification. The receiver sensitivity of 54g™ products far exceeds the specification for maximum range, and transmit power control is included in 54g™ to enable optimized multiple AP deployments. All 54g™ products embed hardware-accelerated AES security, which future-proofs users in advance of the IEEE 802.11i (802.11i) standard due to be adopted next year.

Table 4: 54g™ Pushes the Performance Limits of 802.11g

	54g™	*802.11g Draft Specification*
Highest mandatory data rate	54 Mbps	24 Mbps
Shortest mandatory slot time	9 µs	21 µs
Maximum receiver sensitivity	–92 dBm	–80 dBm
Transmit power control	Included	Not specified
Next generation AES security	Included	Not specified

LOOK FOR THE 54g™ LOGO

Consumers are demanding higher speed WLANs before the IEEE 802.11g draft standard is ratified and before the Wi-Fi Alliance certifies IEEE 802.11g interoperability. The 54g™ logo provides consumers with an easy way to find high-performance WLANs based on the 802.11g draft specification, and protects them from investing in 802.11g solutions where the highest data rate connectivity is less than 54 Mbps. Major wireless networking and PC vendors are shipping 54g™-based products, ensuring a broad selection of compatible, high-performance products. For more information, visit www.54g.org.

Figure 8: 54g™ Logo

The 54g™ logo indicates that a product is a maximum-performance implementation of the draft 802.11g specification, is fully backward compatible with 802.11b products, and is compatible at maximum performance with any other product bearing the 54g™ logo.

CONCLUSION

The IEEE 802.11g standard will drive the next growth wave in wireless networking. Products built to the IEEE 802.11g draft specification are compelling because they:

- Provide a five-fold increase in WLAN speed over current networks
- Remain fully backward compatible with the popular IEEE 802.11b based products
- Offer better range and coverage than current networks

This new WLAN technology provides flexibility, connectivity, mobility, and affordability that is not available through conventional wired solutions.

54g™ is 802.11g implemented at the highest levels of the draft specification, and available today. 54g™ is fully backward compatible with 802.11b. 54g™ products used together provide the highest levels of speed, reach, and security for maximum performance.

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