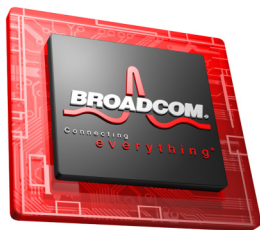


## **802.11n: Next-Generation Wireless LAN Technology**

This white paper explains IEEE 802.11n, the newest draft specification for Wi-Fi®. It is designed to provide an overview of the technology, describe new techniques used to achieve greater speed and range, and identify applications, products, and environments that will benefit from the technology.

April 2006



## Overview

Demand for wireless LAN hardware has experienced phenomenal growth during the past several years, evolving quickly from novelty into necessity. As a measure of this expansion, WLAN chipset shipments in 2005 surpassed the 100-million-unit mark, a more than tenfold increase from 2001 shipments of less than 10 million units.

Thus far, demand has been driven primarily by users connecting notebook computers to networks at work and to the Internet at home as well as at coffee shops, airports, hotels, and other mobile gathering places. As a result, Wi-Fi® technology is most commonly found in notebook computers and Internet access devices such as routers and DSL or cable modems. In fact, more than 90 percent of all notebook computers now ship with built-in WLAN.

The growing pervasiveness of Wi-Fi is helping to extend the technology beyond the PC and into consumer electronics applications like Internet telephony, music streaming, gaming, and even photo viewing and in-home video transmission. Personal video recorders and other A/V storage appliances that collect content in one spot for enjoyment around the home are accelerating this trend.

These new uses, as well as the growing number of conventional WLAN users, increasingly combine to strain existing Wi-Fi networks. Fortunately, a solution is close at hand. The industry has come to an agreement on the components that will make up 802.11n, a new WLAN standard that promises both higher data rates and increased reliability, and the IEEE standards-setting body is ironing out the final details. Though the specification is not expected to be finalized before 2007, the draft is proving to be reasonably stable as it progresses through the formal IEEE review process.

In the meantime, hardware that conforms to the 802.11n draft is becoming available, so consumers can begin building high-speed wireless networks in anticipation of the standard while ensuring interoperability at high speeds and still supporting their existing WLAN hardware.

The purpose of this white paper is to explain the impending 802.11n standard and how it will enable WLANs to support emerging media-rich applications. The paper will also detail how 802.11n compares with existing WLAN standards and offer strategies for users considering higher-bandwidth alternatives.

## Wi-Fi® Standards Comparison

The first WLAN standard to become accepted in the market was 802.11b, which specifies encoding techniques that provide for raw data rates up to 11 Mbps using a modulation technique called Complementary Code Keying, or CCK, and also supports Direct-Sequence Spread Spectrum, or DSSS, from the original 802.11 specification. The 802.11a standard, defined at about the same time as 802.11b, uses a more efficient transmission method called Orthogonal Frequency Division Multiplexing, or OFDM. OFDM, as implemented in 802.11a, enabled raw data rates up to 54 Mbps. Despite its higher data rates, 802.11a never caught on as the successor to 802.11b because it resides on an incompatible radio frequency band: 5 GHz versus 2.4 GHz for 802.11b.

**Note:** All of the WLAN standards provide for multiple transmission options, so that the network can drop to lower (albeit easier to maintain) data rates as environmental interference challenges communications. In the most favorable circumstances, 802.11a and 802.11b support data rates up to 54 Mbps and 11 Mbps respectively.)

In June 2003, the IEEE ratified 802.11g, which applied OFDM modulation to the 2.4-GHz band. This combined the best of both worlds: raw data rates up to 54 Mbps on the same radio frequency as the already popular 802.11b. WLAN hardware built around 802.11g was quickly embraced by consumers and businesses seeking higher bandwidth. In fact, consumers were so eager for a higher-performing alternative to 802.11b that they began buying WLAN client and access-point hardware nearly a year before the standard was finalized.

Today, the vast majority of computer network hardware shipping supports 802.11g. Increasingly, as technology improves and it becomes easier and less costly to support both 2.4 GHz and 5 GHz in the same chipset, dual-band hardware is becoming more commonplace. Much of the WLAN client hardware available today, in fact, supports both 802.11a and 802.11g.

A similar scenario to the draft 802.11g phenomenon is now unfolding with 802.11n. The industry came to a substantive agreement with regard to the features to be included in the high-speed 802.11n standard in early 2006. And though it will likely be 2007 before the standard is ratified, the specification is stable enough for draft-n Wi-Fi cards and routers to already be making their way to store shelves.

## 802.11n: A Menu of Options

The emerging 802.11n specification differs from its predecessors in that it provides for a variety of optional modes and configurations that dictate different maximum raw data rates. This enables the standard to provide baseline performance parameters for all 802.11n devices, while allowing manufacturers to enhance or tune capabilities to accommodate different applications and price points. With every possible option enabled, 802.11n could offer raw data rates up to 600 Mbps. But WLAN hardware does not need to support every option to be compliant with the standard. In 2006, for example, most draft-n WLAN hardware available is expected to support raw data rates up to 300 Mbps.

In comparison, every 802.11b-compliant product must support data rates up to 11 Mbps, and all 802.11a and 802.11g hardware must support data rates up to 54 Mbps.

### Better OFDM

In the 802.11n draft, the first requirement is to support an OFDM implementation that improves upon the one employed in the 802.11a/g standards, using a higher maximum code rate and slightly wider bandwidth. This change improves the highest attainable raw data rate to 65 Mbps from 54 Mbps in the existing standards.

### MIMO Improves Performance

One of the most widely known components of the draft specification is known as Multiple Input Multiple Output, or MIMO. MIMO exploits a radio-wave phenomenon called *multipath*: transmitted information bounces off walls, doors, and other objects, reaching the receiving antenna multiple times via different routes and at slightly different times. Uncontrolled, multipath distorts the original signal, making it more difficult to decipher and degrading Wi-Fi performance. MIMO harnesses multipath with a technique known as *space-division multiplexing*. The transmitting WLAN device actually splits a data stream into multiple parts, called *spatial streams*, and transmits each spatial stream through separate antennas to corresponding antennas on the receiving end. The current 802.11n draft provides for up to four spatial streams, even though compliant hardware is not required to support that many.

Doubling the number of spatial streams from one to two effectively doubles the raw data rate. There are trade-offs, however, such as increased power consumption and, to a lesser extent, cost. The draft-n specification includes a MIMO power-save mode, which mitigates power consumption by using multiple paths only when communication would benefit from the additional performance. The MIMO power-save mode is a required feature in the draft-n specification.

## MIMO Enhancements

There are two features in the draft-n specification that focus on improving MIMO performance, called *beam-forming* and *diversity*. Beam-forming is a technique that focuses radio signals directly on the target antenna, thereby improving range and performance by limiting interference.

**Table 1. Major Components of Draft 802.11n**

Feature	Definition	Specification Status
<b>Better OFDM</b>	Supports wider bandwidth & higher code rate to bring maximum data rate to 65 Mbps	Mandatory
<b>Space-Division Multiplexing</b>	Improves performance by parsing data into multiple streams transmitted through multiple antennas	Optional for up to four spatial streams
<b>Diversity</b>	Exploits the existence of multiple antennas to improve range and reliability. Typically employed when the number of antennas on the receiving end is higher than the number of streams being transmitted.	Optional for up to four antennas
<b>MIMO Power Save</b>	Limits power consumption penalty of MIMO by utilizing multiple antennas only on as-needed basis	Required
<b>40 MHz Channels</b>	Effectively doubles data rates by doubling channel width from 20 MHz to 40 MHz	Optional
<b>Aggregation</b>	Improves efficiency by allowing transmission bursts of multiple data packets between overhead communication	Required
<b>Reduced Inter-frame Spacing (RIFS)</b>	One of several draft-n features designed to improve efficiency. Provides a shorter delay between OFDM transmissions than in 802.11a or g.	Required
<b>Greenfield Mode</b>	Improves efficiency by eliminating support for 802.11a/b/g devices in an all draft-n network	Currently optional

Diversity exploits multiple antennas by combining the outputs of or selecting the best subset of a larger number of antennas than required to receive a number of spatial streams. This is important because the draft-n specification supports up to four antennas, so devices will probably encounter others built with a different number of antennas. A notebook computer with two antennas, for example, might connect to an access point with three antennas. In this case, only two spatial streams can be used even though the access point itself may be capable of three spatial streams.

With diversity, surplus antennas are put to good use. The device with more antennas uses the extra ones to operate at longer range. For example, the outputs of two antennas may be combined to receive one spatial stream to achieve a longer link range. The concept may be extended to combine the outputs of three antennas to receive two spatial streams for higher data rate and range and so on.

Diversity is not restricted to 802.11n or even WLAN. It can be used to improve any

type of radio communication. In fact, diversity has typically been implemented in some existing 802.11a, 802.11b, and 802.11g hardware through selection of the best of two antennas.

### Improved Throughput and Higher Data Rates

Another optional mode in the 802.11n draft effectively doubles data rates by doubling the width of a WLAN communications channel from 20 MHz to 40 MHz. The primary trade-off here is fewer channels available for other devices. In the case of the 2.4-GHz band, there is enough room for three non-overlapping 20-MHz channels. Needless to say, a 40-MHz channel does not leave much room for other devices to join the network or transmit in the same airspace. This means intelligent, dynamic management is critical to ensuring that the 40-MHz channel option improves overall WLAN performance by balancing the high-bandwidth demands of some clients with the needs of other clients to remain connected to the network.

This paper has covered many of the major mandatory and optional features of the draft 802.11n specification, though coverage is by no means exhaustive. Other optional features that draft-n hardware may support, for example, include *high-throughput duplicate mode*, which helps extend the network's range, and *short guard interval*, which improves efficiency by further limiting overhead.

With all the optional modes and back-off alternatives, the array of possible combinations of features and corresponding data rates can be overwhelming. To be precise, the current 802.11n draft provides for 576 possible data rate configurations. In comparison, 802.11g provides for 12 possible data rates, while 802.11a and 802.11b specify eight and four, respectively.

Table 2 compares the primary IEEE 802.11 specifications.

**Table 2. Primary IEEE 802.11 Specifications**

	<b>802.11a</b>	<b>802.11b</b>	<b>802.11g</b>	<b>802.11n</b>
<b>Standard Approved</b>	July 1999	July 1999	June 2003	Not yet ratified
<b>Maximum Data Rate</b>	54 Mbps	11 Mbps	54 Mbps	600 Mbps
<b>Modulation</b>	OFDM	DSSS or CCK	DSSS or CCK or OFDM	DSSS or CCK or OFDM
<b>RF Band</b>	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz or 5 GHz
<b>Number of Spatial Streams</b>	1	1	1	1, 2, 3, or 4
<b>Channel Width</b>	20 MHz	20 MHz	20 MHz	20 MHz or 40 MHz

## Coexisting with Today's WLANs

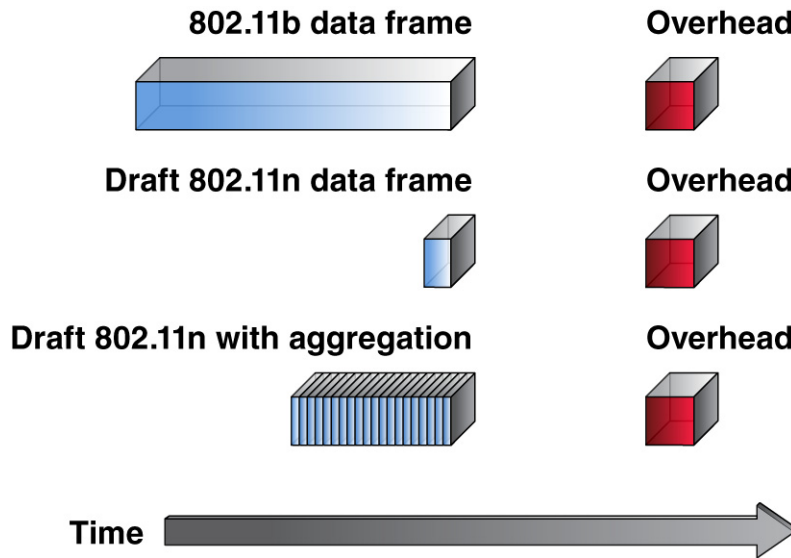
The draft 802.11n specification was crafted with the previous standards in mind to ensure compatibility with more than 200 million Wi-Fi devices currently in use. A draft-n access point will communicate with 802.11a devices on the 5-GHz band as well as 802.11b and 802.11g hardware on the 2.4-GHz frequencies. In addition to basic interoperability between devices, 802.11n provides for greater network efficiency in mixed mode over what 802.11g offers.

Network efficiency is basically the proportion of the available bandwidth that is used to transmit data as opposed to *overhead* or protocols used to manage network communications. Wireless environments are much more challenging to orchestrate than wired networks, so there is generally more overhead to ensure that data sent is actually received, and that other clients leave the channel open during transmission.

The presence of 802.11b nodes makes communications difficult on the 2.4-GHz band because the older standard does not recognize OFDM, which is employed by 802.11g and draft-n. This means that if OFDM clients want to communicate in the presence of 802.11b clients, they need to use the older standard's communication protocol at least to protect their higher-rate OFDM transmissions. This drops network efficiency considerably because data packets take far less time to transmit with 802.11g and draft-n than they do under the old 802.11b standard.

Some WLAN chipset suppliers, including Broadcom, devised innovative schemes to improve the efficiency of mixed 802.11b/g networks. Fortunately, the issue is addressed directly in the draft-n specification.

One of the most important features in the draft-n specification to improve mixed-mode performance is *aggregation*. Rather than sending a single data frame, the transmitting client bundles several frames together. Thus, aggregation improves efficiency by restoring the percentage of time that data is being transmitted over the network, as Figure 1 illustrates.



**Figure 1: How Aggregation Improves Efficiency in a Mixed-Mode Network**

It is much easier for draft-n devices to coexist with 802.11g and 802.11a hardware because they all use OFDM. Even so, there are features in the specification that increase efficiency in OFDM-only networks. One such feature is Reduced Inter-Frame Spacing, or RIFS, which shortens the delay between transmissions.

For the best possible performance, the draft-n specification provides for what is called *greenfield* mode, in which the network can be set to ignore all earlier standards. It is not clear at this stage whether greenfield mode will be a mandatory or an optional feature in the final 802.11n draft, but it is likely to be an option.

Realistically, battery-powered WLAN hardware will continue to be built around 802.11g and even 802.11b for some time. Despite the improved efficiency built into the draft-n specification, however, it is difficult to eliminate all of the obstacles of 802.11b. This means that consumers looking for the best possible network performance may want to consider replacing 802.11b WLAN hardware on their networks.



## Consumer Applications Demand 802.11n

Because it promises far greater bandwidth, better range, and reliability, 802.11n is advantageous in a variety of network configurations. And as emerging networked applications take hold in the home, a growing number of consumers will come to view 802.11n not just as an enhancement to their existing network, but as a necessity.

With most Internet connection speeds below 5 Mbps, it is unlikely that consumers who use WLAN technology simply to pair a single computer with an Internet connection are taxing their existing network, at least when used at close range. Even this class of consumer may be pleasantly surprised by the increase in range and reliability that an upgrade to draft-n WLAN hardware can offer. Some of the current and emerging applications that are driving the need for 802.11n are Voice over IP (VoIP), streaming video and music, gaming, and network attached storage.

VoIP is mushrooming as consumers and businesses alike realize they can save money on long-distance phone calls by using the Internet instead of traditional phone service. An increasingly popular way to make Internet calls is with VoIP phones, which are battery-powered handsets that typically connect to the Internet with built-in 802.11b or 802.11g. Telephony does not demand high bandwidth, although it does require a reliable network connection to be usable. Both 802.11b and 802.11g consume less power than 802.11n in MIMO modes, but single-stream 802.11n may become prevalent in VoIP phones. VoIP phones can benefit today from the increased range and reliability of a draft-n access point.

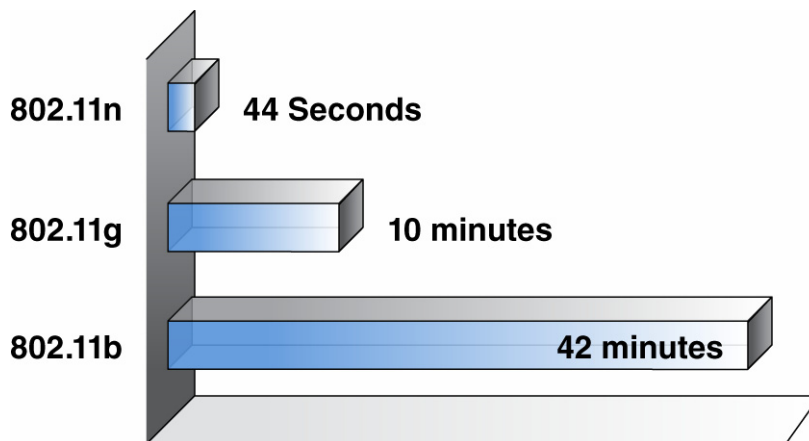
As with voice, streaming music is an application that requires a highly reliable connection that can reach throughout the home. Millions of consumers are building libraries of digital music on their personal computers by ripping their CD collections and buying digital recordings over the Internet. In addition, growing numbers are streaming music directly from the Internet.

As their digital music collections grow, more consumers find they would like to be able to listen to it through living room stereos or via players in other rooms around the house. Though higher bandwidth is not absolutely necessary, the additional range and reliability that draft-n offers may be better suited to streaming music than older-generation WLAN hardware.

Gaming is an application that increasingly is making use of home WLANs, whether users connect wirelessly to the Internet from their computers and portable gaming devices or use the network to compete with others in the home.

A growing application that demands all that 802.11n has to offer—high data rates as well as range and reliability—is Network-Attached Storage, or NAS. NAS has become popular in the enterprise as an inexpensive, easy-to-install alternative for data backup. More recently, NAS is taking hold in small offices and even some homes, as users want to safeguard their growing digital photo albums from hard-drive failure, and as the price of self-contained NAS backup systems falls well below \$1,000. New, more exciting applications for NAS are emerging, such as video storage centers that demand reliable, high-bandwidth connections to stream prerecorded TV shows, music videos and full-length feature films to televisions and computers throughout the house.

Transferring large files such as prerecorded TV shows from a personal video recorder onto a notebook computer or portable media player for viewing outside the home takes planning and patience on an older WLAN. Figure 2 compares the time it would take to transfer a 30-minute video file. At the best data transfer rate, it would take 42 minutes to copy the file using 802.11b, and less than a minute with a two-antenna draft-n client.



**Figure 2: Time (Best Case) to Transfer 30-Minute HD Video.**

The enterprise may have the most to gain from the higher raw data rates that the draft-n standard promises. Knowledge workers have grown accustomed to the benefits of WLANs in the office. They can carry their notebooks to conference rooms, coworkers' desks, even break areas, and still have access to e-mail, instant messaging, and the Internet, as well as corporate data.

But some everyday applications such as transferring large files from a group server, accessing corporate databases, and system backups, can be painstakingly slow on a 54-Mbps WLAN. For such high-traffic applications, many otherwise untethered workers anchor their computers to an Ethernet cable, which connects to the network at 100 Mbps or even 1 Gbps. With draft-n hardware, users can have the best of both worlds: the speed of wired Ethernet and the mobility of WLAN.

## Recommendations

As is evident from the previous section, virtually all enterprises could benefit today from higher-bandwidth WLANs. Nevertheless, many large businesses are expected to wait until 802.11n is ratified before initiating large deployments of the new standard. Corporations that are ready to deploy, as well as consumers and smaller businesses anxious to take advantage of the higher data rates and improved range and reliability, should shop carefully. Not all WLAN hardware featuring MIMO, diversity, and other 802.11n-like features can claim to be compliant with the emerging standard. Buyers should look for products that say "IEEE 802.11n Draft Compliant."

Buyers should also keep in mind that there are a host of optional features in the draft-n specification. Many of them, such as channelization and greenfield mode, to name a few, are designed to improve raw data rates, and need to be present on both ends of the link in order to be enabled.

There are also differences between how draft-n features are implemented. Some draft-n hardware supporting 40-MHz channelization, for example, is better than others at balancing the demands of high-bandwidth communications for one client with the needs of other users on the network.

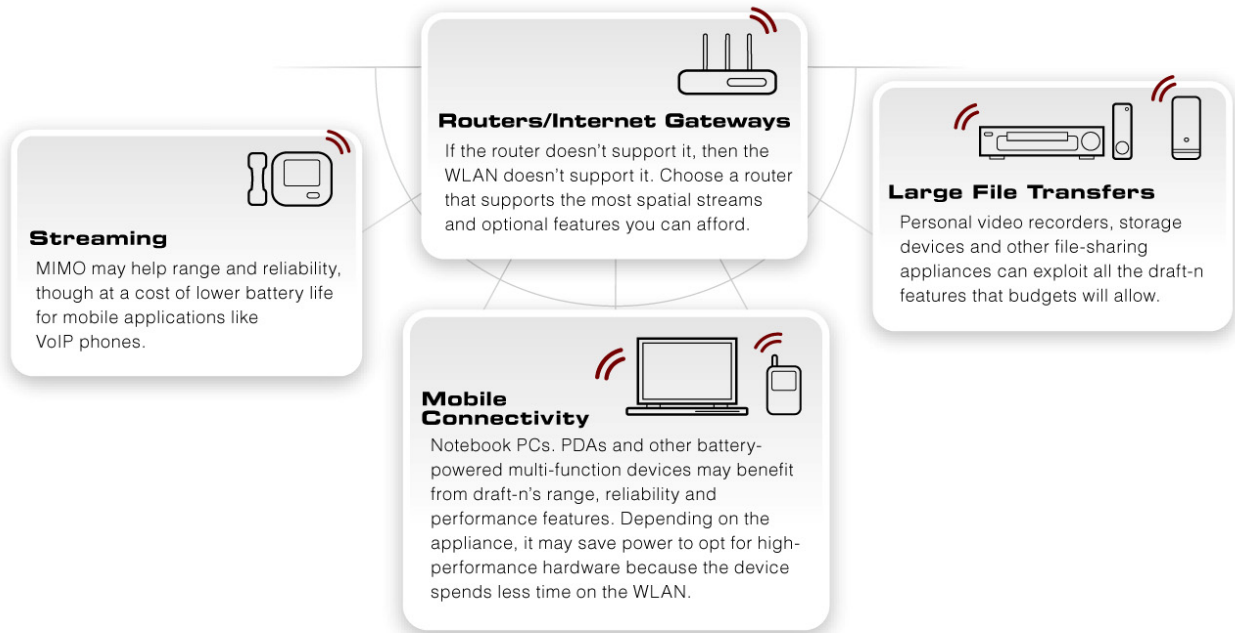
A good strategy for consumers planning to upgrade the data rates and range of their home WLANs is to start with a draft-n router and purchase one that supports the most spatial streams and optional features that budgets allow. Follow a similar strategy for high-bandwidth file-sharing appliances such as personal video recorders and backup storage devices.

For stationary clients that do not need high data rates, for example music players streaming content from a digital home library or the Internet, draft-n may help improve range and reliability.

Selecting the right draft-n alternatives for battery-powered devices may be the trickiest item on the shopping list because power consumption is as important a consideration as data rates, range, and cost. VoIP phones, for example, are low-bandwidth devices that might benefit from MIMO techniques in environments where range and reliability are an issue, but at the cost of battery life.

Notebook computers may benefit from high-performance features like MIMO, channelization and greenfield mode for file transfers and data backups. Keep in mind that with channelization and MIMO power-conservation, which enables multiple spatial streams only when they are needed, performance features may end up saving power in some cases because the notebook is active on the WLAN for shorter periods.

Figure 3 depicts a number of considerations for choosing draft-n WLAN hardware.



**Figure 3: Considerations for Choosing Draft-n WLAN Hardware**

## Why Choose Broadcom for Draft-N?

First and foremost, Broadcom's Intensi-fi™ family of WLAN chipsets is 802.11n draft-compliant. And although the draft-n standard appears to be fairly stable at this stage, the Intensi-fi family is highly programmable, which means it is adaptable to unforeseen and unexpected changes in the specification.

Second, due to Broadcom-designed signal processing techniques, Intensi-fi chipsets feature *Active Diversity*, which gives a network connection between two dual-antenna devices higher performance, range, and reliability without the cost and power consumption of a third antenna on one of the connections.

The fidelity of the Intensi-fi™ radio is second to none, which means it can maintain higher data rates at longer distances and in more adverse conditions.

With regard to the optional 40-MHz channel mode, the Intensi-fi chipset provides superior balance between performance and the needs of other members of the WLAN. Intensi-fi's "good-neighbor" approach to channelization includes frequent scans for other network traffic, along with a mechanism to dip quickly back to all-20-MHz channels when other clients need to communicate.

The Intensi-fi chipset supports the latest standards to secure WLANs, including WPA2 and CCX version 4. In addition, Intensi-fi supports SecureEasySetup™, a one-touch push-button security setup that makes it easy to install a secure WLAN.

Finally, Intensi-fi supports 125 High Speed Mode™ (also known as SpeedBooster), a proprietary high-speed mode in Broadcom's 54g™ 802.11g family of chipsets, as well as BroadRange™ signal processing technology that improves the ability of Wi-Fi devices to extend coverage area. A network can take advantage of 125 High Speed Mode if all WLAN devices in the network include Intensi-fi or 54g™ chipsets. BroadRange™, on the other hand, improves network performance in 802.11g modes regardless of the chipsets inside the other devices on the network.

For added assurance of greatest reliability and best range, choose products built with Intensi-fi™ technology.



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