

IEEE 802.11g Explained

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Summary

The adoption of Intersil's OFDM-based proposal for the IEEE 802.11g Draft Standard is a significant milestone in the continuing development of standards-based WLAN technology. Adoption of the proposal by IEEE 802.11 Task Group G accomplishes two major objectives:

- 1.) OFDM will be deployed at 2.4 GHz as a *mandatory* part of the 802.11g Standard, and it will support data rates up to 54 Mbps
- 2.) Backward compatibility with existing Wi-Fi (802.11b) systems is guaranteed

The Intersil proposal requires use of Orthogonal Frequency Division Multiplexing (OFDM) for higher data rates (>20 Mbps) and requires support for Complimentary Code Keying (CCK) to ensure backward compatibility with existing 802.11b radios as *mandatory* elements of the 802.11g Draft Standard. The final version of the Intersil proposal, adopted on the second ballot at the Austin IEEE 802 meeting in November, had some optional features designed to increase its appeal to the voting body.

The *optional* elements included in the 802.11g Draft Standard are:

- a.) **CCK/OFDM:** a hybrid of CCK and OFDM designed to facilitate use of the OFDM waveform while supporting backward compatibility with existing CCK radios. CCK is used to transmit the packet preamble/header and OFDM is used to transmit the payload. CCK/OFDM supports data rates up to 54 Mbps. The distinctions between OFDM and CCK/OFDM are explained in more detail below.
- b.) **PBCC:** a "single carrier" solution backed by Texas Instruments (TI). This waveform can also be described as a hybrid. It uses the CCK to transmit the header/preamble portion of each packet and PBCC to transmit the payload. PBCC supports data rates up to 33 Mbps.

It is important to bear in mind that every 802.11g device must support both CCK and OFDM. Those choosing to implement 802.11g solutions may include either of the two optional elements above, or they may elect to include only the mandatory elements (CCK and OFDM) and exclude *both* optional elements.

Who Benefits?

Although some have tried to position 802.11g as a competitor to 802.11a, Intersil has long held that this is simply not the case. Instead, we see the two technologies as complimentary. There is more available spectrum at 5 GHz, which allows for more channels and, by extension, can support more users. On the other hand, 802.11g systems provide backward compatibility with existing Wi-Fi devices and will offer a range advantage relative to systems operating at 5 GHz. Both technologies share a common high rate waveform, namely OFDM. Therefore, 802.11a and 802.11g have respective strengths customers are now free to choose from.

The IEEE 802.11g Draft Standard offers important near-term and long-term benefits. In the near term, the main beneficiaries of 802.11g technology will be those who have existing Wi-Fi equipment. At present, there are more than 15 million Wi-Fi devices world-wide, and this number will likely double by the end of 2002. Wi-Fi currently dominates the WLAN market with nearly a 100% share. In other words, it's going to be around for a long time to come.

IEEE 802.11g brings higher data rates (up to 54 Mbps) to the 2.4 GHz band and of equal importance, it ensures backward compatibility with existing Wi-Fi equipment. For owners of existing Wi-Fi equipment, IEEE 802.11g provides a smooth migration path to higher data rates, thus extending the life of 2.4 GHz equipment. In a recent article, Alan Noguee of Cahners In-Stat Group commented on this point:

"I think g is really going to help move along b, especially in areas where the data rate of b was holding it back," Noguee said, adding that he ultimately expects wireless networking kits that incorporate both 802.11a and 802.11g to be available.

http://dailynews.yahoo.com/h/nm/20011116/wr/tech_wireless_standard_dc_1.html

Mr. Noguee's comments also touch on the increasingly evident trend toward the adoption of dual band devices capable of operating in either the 2.4 or 5 GHz bands. Very early in the process of developing the 802.11g Draft Standard, Intersil began pointing out that the use of OFDM in the 2.4 GHz band will actually facilitate development of dual band radios. Indeed, this is the main long term benefit of the 802.11g Draft Standard.

The reason 802.11g facilitates development of dual band devices is really quite simple. In order to build a dual band radio, developers will need to include OFDM capability to support 802.11a operation at 5 GHz and CCK capability to support Wi-Fi at 2.4 GHz. By using OFDM as the high rate extension at 2.4 GHz (as opposed to a third waveform), implementing 802.11g in a dual band device adds no additional complexity in terms of hardware.

The IEEE 802.11g Draft Standard

The Draft Standard adopted at the November IEEE 802 meeting in Austin contains both mandatory and optional elements. In order to gain a thorough understanding of the impact 802.11g is likely to have, it's important to be aware of exactly what is mandatory and what is optional:

- 1.) The 802.11g Draft Standard ensures that OFDM will be deployed in standards-based solutions in the 2.4 GHz band. OFDM is a mandatory part of the Draft Standard.
- 2.) Backward compatibility with existing 2.4 GHz Wi-Fi (802.11b) radios is a mandatory requirement.
- 3.) The 802.11g Draft Standard includes both PBCC and CCK/OFDM as optional elements. Implementations will be required to include both CCK and OFDM, but need not include either option.

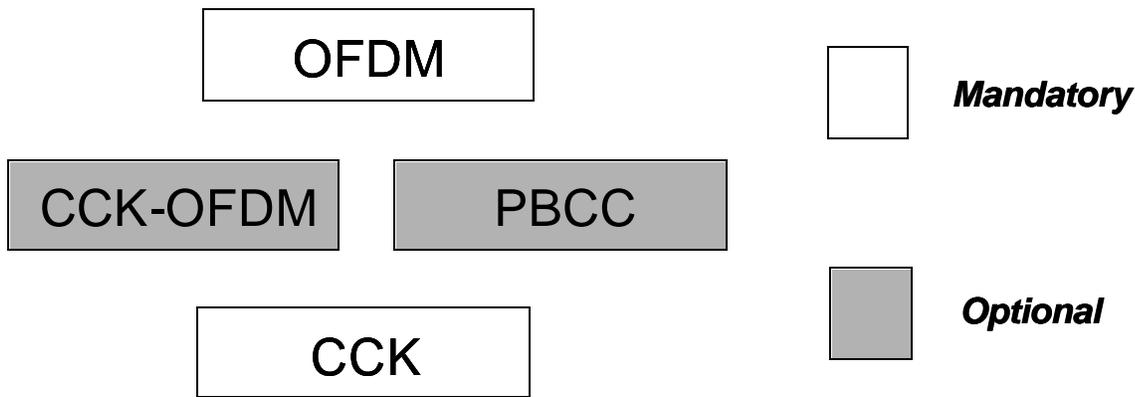


Figure 1 IEEE 802.11g Draft Standard Contains Mandatory and Optional Elements

The mandatory and optional elements of the Draft Standard are represented graphically in Figure 1. The following paragraphs briefly describe each element of the IEEE 802.11g Draft Standard. Technical jargon is minimized, but cannot be completely avoided.

Packet Structure: Preambles, Payloads & Other Weird Stuff

For the purposes of the following discussion, it's helpful to bear in mind that every packet of transmitted data can be thought of as consisting of two main parts:

- 1.) Preamble/Header
- 2.) Payload

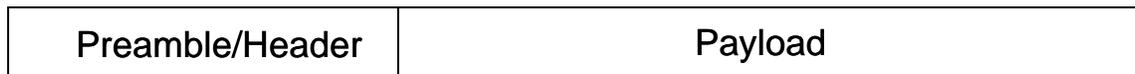


Figure 2 Every Packet Includes a Preamble/Header and a Payload

The Preamble/Header serves to alert all radios sharing a given channel that data transmission is beginning. The Preamble is a known sequence of 1's and 0's that allows time for the radios to get ready to receive data (think of it as a wake-up call). When the Preamble is complete, the receiver must be ready to receive data. The Header immediately follows the Preamble and conveys several important pieces of information. Among these is the length (in ?sec) of the payload. This is important, since it tells every other receiver that can "hear" the Preamble/Header the length of the transmission which follows. Other radios will not begin transmission during this period, thus preventing a network collision.

The payload can vary significantly in length, depending on the data rate and the number of bytes being transmitted. Payloads can be very short (as few as 64 bytes) or very long (up to 1500 bytes). In most cases, the Preamble/Header and the Payload are sent using the same modulation format (CCK for example). However, as discussed below, there are exceptions to this rule in the optional elements of the 802.11g Draft Standard.

CCK

Complimentary Code Keying (CCK) is the basic modulation format for current Wi-Fi (IEEE 802.11b) systems. CCK is a “single carrier” system. In other words, all of the data is transmitted by modulating a single radio frequency, or carrier, as shown in Fig. 3.

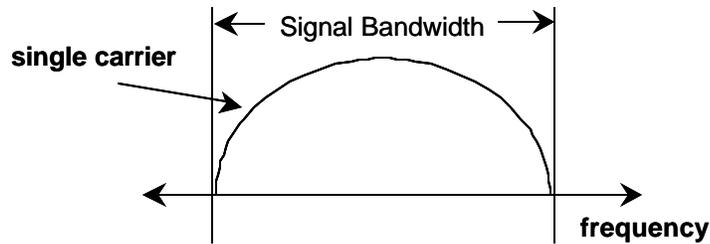


Figure 3 CCK is a “Single-Carrier” Modulation Format

When using CCK modulation, the Preamble/Header and the Payload are both transmitted using CCK modulation (Fig. 4).

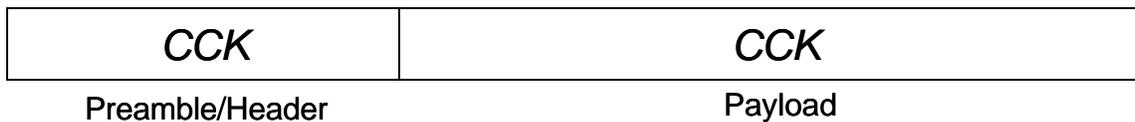


Figure 4 Current Wi-Fi Systems Use CCK for Both the Preamble/Header and the Payload

OFDM

Orthogonal Frequency Division Multiplexing is a technology that is just now beginning to reach the wireless LAN (WLAN) market in the form of IEEE 802.11a devices operating in the 5 GHz band. Until very recently, FCC regulations prevented the use of OFDM in the 2.4 GHz band. That changed in May of 2001. Now that OFDM is approved for use in the 2.4 GHz band, using a single modulation format for both the 2.4 and 5 GHz bands is possible.

OFDM is a “multi-carrier” modulation scheme. The data is split up among several closely spaced “subcarriers” (see Figure 5). By doing so, OFDM systems are able to provide very reliable operation even in environments that result in a high degree of signal distortion due to multipath. In addition, OFDM systems can support higher data rates than single carrier systems without incurring a huge penalty in terms of system complexity. For data rates up to 11 Mbps, CCK is a very good choice. However, as data rates go higher, OFDM becomes a better choice. OFDM was selected for use in the 5 GHz bands primarily because it enabled data rates up to 54 Mbps to be realized.

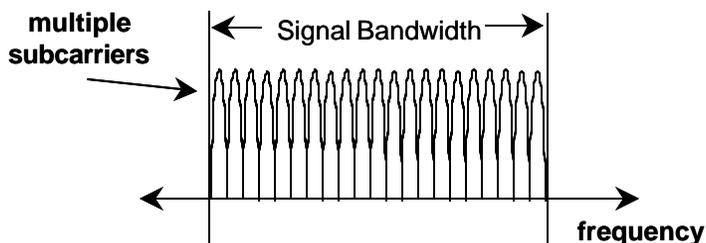


Figure 5 OFDM Systems Transmit Data on Multiple “Subcarriers”

Another significant feature of OFDM modulation is the shorter Preamble length. The CCK Preamble is 72 μ sec in length. By comparison, an OFDM Preamble is just 16 μ sec in length. A shorter preamble is desirable because it results in less “overhead” on the network. Although the Preamble is an absolutely essential part of the data packet, it takes up time and thereby reduces the amount of time available for transmitting data. OFDM allows a shorter packet preamble to be used, thereby leaving more time for data transmission (a good thing!). OFDM systems use OFDM for both the Preamble/Header and the Payload.

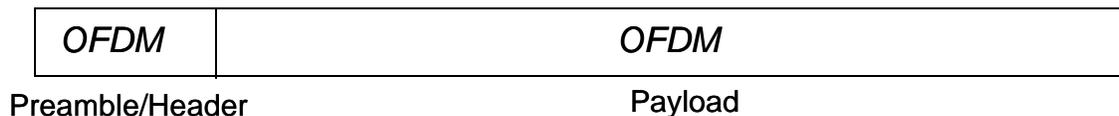


Figure 6 OFDM Systems Use Shorter Preambles to Reduce Network Overhead

CCK/OFDM

As the name implies, CCK/OFDM is a hybrid. It is included as an optional part of the IEEE 802.11g Draft Proposal. As shown in Figure 7, CCK/OFDM uses CCK modulation to transmit the Preamble/Header and OFDM to transmit the Payload. Note that the CCK and OFDM modulation formats remain separate and distinct. A transition from CCK modulation to OFDM modulation is made between the Preamble/Header and the Payload.

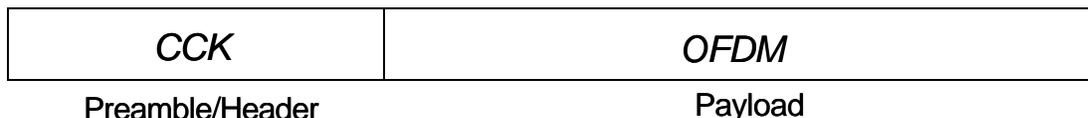


Figure 7 CCK/OFDM Uses the CCK Preamble/Header with an OFDM Payload

This begs a rather obvious question: “Why would we do this?” As it turns out, there were very good reasons for developing the optional hybrids included in the 802.11g Draft Standard. When operating in the presence of existing Wi-Fi devices, the CCK header is transmitted to alert all Wi-Fi devices that a transmission is about to begin and to inform those devices of the duration (in μ sec) of that transmission. The Payload can then be transmitted at a much higher rate using OFDM. Even though existing Wi-Fi devices will not be capable of receiving the Payload, any collisions will be prevented by the fact that these devices can coexist with newer IEEE 802.11g devices using CCK/OFDM modulation. Use of the CCK Preamble results in more overhead than devices using an OFDM Preamble. However, this is still a reasonable trade-off because CCK/OFDM radios will enable higher data rates (>20 Mbps) that more than offset any overhead penalty while preserving backward compatibility with existing CCK systems.

It must be kept in mind that CCK/OFDM is only an option in the adopted IEEE 802.11g Draft Standard. The mandatory OFDM waveform can also coexist and interoperate with existing Wi-Fi devices. However, a different method referred to as “RTS/CTS” is required. This method is described in greater detail below.

PBCC

Packet Binary Convolutional Coding is a single carrier system, but it is far different from CCK. It employs a more complex signal constellation (8-PSK for PBCC vs. BPSK/QPSK for CCK) and a convolutional code structure vs. the block code structure used in CCK. Thus, the decoding mechanism is entirely different. Like CCK/OFDM, PBCC is a hybrid waveform. That is to say, it uses a CCK Preamble/Header with a PBCC payload (see Figure 8). This enables higher data rates while preserving backward compatibility with existing Wi-Fi systems in the same manner as described for CCK/OFDM above.

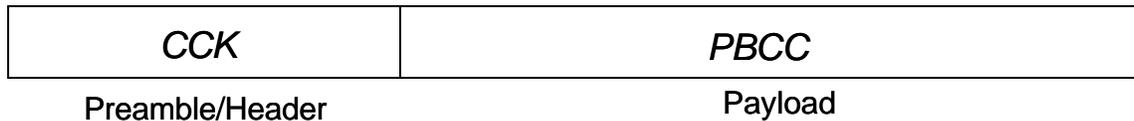


Figure 8 PBCC is a Hybrid Combining a CCK Preamble/Header with a PBCC Payload

The maximum data rate for PBCC as included in the IEEE 802.11 Draft Standard is 33 Mbps. Therefore, the peak data rates for the optional PBCC waveform are lower than either the mandatory OFDM waveform or the other optional waveform (CCK/OFDM). It should be pointed out that PBCC was included as an optional element of the original IEEE 802.11b Standard, though no systems using this waveform were brought to market.

OFDM Interoperability With Wi-Fi Devices

A LOT of ground has been covered to this point. A quick review of salient points of the IEEE 802.11g Draft Standard are in order:

- 1.) Support for CCK modulation is **MANDATORY** in order to ensure backward compatibility with existing Wi-Fi systems
- 2.) Support for OFDM modulation is **MANDATORY** for data rates >20 Mbps
- 3.) Both CCK/OFDM and PBCC are **OPTIONAL**. Vendors can choose to implement PBCC, CCK/OFDM, or **NO OPTION AT ALL**.

Given that the mandatory OFDM waveform is capable of data rates up to 54 Mbps, it is very likely that many IEEE 802.11g radios will implement the mandatory modes only, and not include either of the optional elements. This section describes how radios using OFDM modulation (OFDM Preamble/Header and OFDM Payload) can interoperate with existing Wi-Fi radios (CCK Preamble/Header and CCK Payload).

Listen-Before-Talk

The basic problem is that existing Wi-Fi radios are not capable of demodulating OFDM transmissions. Under normal conditions, all of the radios on a given channel share access to the airwaves by means of a “listen-before-talk” mechanism. The technical term for this mechanism is Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA). In simple terms, the radios listen to determine if another device is transmitting. Each radio on a channel waits until there is no other transmission in progress before beginning to transmit. There are additional provisions to reduce the probability that more than one radio will attempt to transmit at the same moment.

IEEE 802.11g radios will be able to receive either CCK or OFDM transmissions. However, existing Wi-Fi devices can only receive CCK transmissions. This presents a problem: If existing radios cannot receive OFDM transmissions, how will they avoid colliding with those same transmissions? Simply put, existing Wi-Fi radios cannot “hear” OFDM transmissions. Due to this fact, use of the normal CSMA/CA, or listen-before-talk mechanism will not be suitable when CCK radios and OFDM radios operate on the same channel. Fortunately, another mechanism already exists in the 802.11 protocol that can address this problem very efficiently.

The Hidden Node Problem and RTS/CTS

Under normal operating conditions, all radios sharing a given channel (including the Access Point) can hear one another. However, this is not always the case. There are instances when all radios can hear and be heard by the Access Point (AP), but they cannot hear every other node on the channel (see Fig. 9). Under these conditions, the listen-before-talk mechanism would break down because radios might detect a clear channel and begin transmitting to the AP while the AP is already in the process of receiving another transmission from a “hidden” radio. This is commonly referred to as the “hidden node” problem.

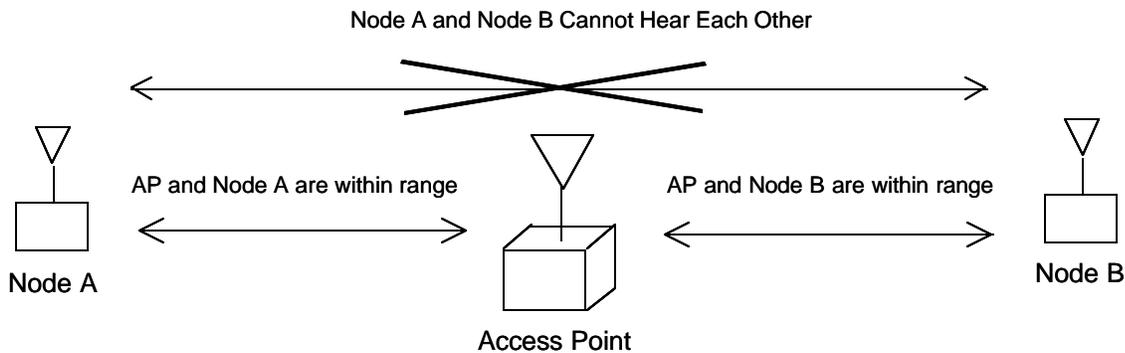


Figure 9 Hidden Node Problem Occurs When Some Radios Cannot “Hear” Each Other

Due to this problem, another mechanism called Request-To-Send / Clear-To-Send (RTS/CTS) was included in the existing 802.11 Standard. Under the RTS/CTS mechanism, each node must send an RTS message to the AP and receive a CTS reply before transmission can begin. The situation of CCK and OFDM radios operating on the same channel is very analogous to the “Hidden Node” problem because the CCK radios cannot “hear” the OFDM transmissions. However, via the use of the RTS/CTS mechanism, OFDM radios will be able to operate on the same channel as existing Wi-Fi radios without collision.

The RTS/CTS mechanism does result in additional network overhead. However, the penalty is actually quite modest. The benefit is a migration path to higher data rates for radios operating on the 2.4 GHz band. In the future, networks may make exclusive use of OFDM in the 2.4 GHz band, thus removing the need to use RTS/CTS at some point.

Conclusions

Adoption of the 802.11g Draft Standard is extremely beneficial for the WLAN market as a whole. OFDM has been adopted as the MANDATORY high rate waveform in the 2.4 GHz band. Data rates of up to 54 Mbps are now available in the 2.4 GHz band. In addition, backward compatibility with existing Wi-Fi devices is assured. In the near term, providing a migration paths to higher data rates in the 2.4 GHz band is the main advantage of 802.11g.

In addition to the mandatory use of OFDM for data rates >20 Mbps, there are two optional waveforms: CCK/OFDM and PBCC. It must be emphasized that while IEEE 802.11g radios MUST be capable of using OFDM, they need not implement either of the two options. Therefore the majority of 802.11g implementations will likely include the mandatory elements. In the case of the optional PBCC waveform, the peak data rate is 33 Mbps as compared to 54 Mbps for OFDM. Thus, the optional PBCC waveform is actually slower than the peak data rates for the mandatory OFDM waveform.

In the longer term, the IEEE 802.11g Draft Standard also represents an important step toward the realization of dual band (2.4 GHz and 5 GHz) radios. Because OFDM is already required for operation in the 5 GHz band, implementing 802.11g in a dual band devices adds no extra hardware complexity to the resulting product. For dual band devices, "*G is free!*".