

## ***The ABC's of 2.4 and 5 GHz Wireless LANs***

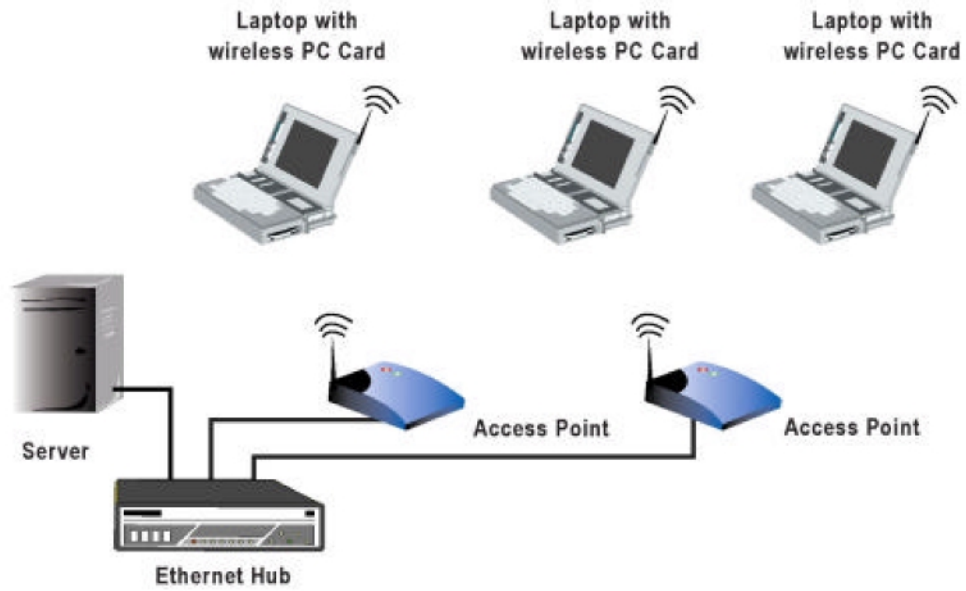
*By: Amit Dhir, Xilinx, Inc.*

---

The enterprise, SOHOs, and homes are demanding mobility and portability with high-bandwidth data, voice, and video access. This has led to the introduction of wireless LAN technologies, which attempt to provide exactly that. In the 2.4 GHz frequency band, IEEE 802.11b is “the” wireless LAN solution in the market. However the 5 GHz frequency has two possible contending technologies — IEEE 802.11a and HiperLAN2. This white paper explains the state of affairs in the wireless LAN market, the underlying technology behind the different types of wireless LANs, the over-utilized 2.4 GHz spectrum, the migration to 5 GHz band, which technology will succeed, and how Xilinx Spartan-II FPGAs are ideal for this market place.

## Introduction

A wireless local area network (WLAN) is a flexible-data communications system implemented as an extension to or as an alternative for, a wired LAN. Using radio frequency (RF) technology, WLANs transmit and receive data over the air, minimizing the need for wired connections. Much like base stations for cellular technology, WLANs use access point (AP) to provide wireless access to mobile terminals (MTs) or other devices in the network. These APs are either connected to other APs, to other wired networks such as Ethernet or connected to a broadband access medium such as DSL, cable, T1, etc. (shown in **Figure 1**).



*Figure 1: Wireless LAN Configuration*

WLANs are a rapidly emerging market. They combine data connectivity with user mobility and provide a connectivity alternative for a broad range of consumers and business customers. They have a strong popularity in vertical markets such as telecommuting, SOHOs, health-care, retail, manufacturing, warehousing, and academia, where productivity gains are realized by using hand-held terminals and notebook PCs to transmit real-time information to centralized hosts for processing. Business Research Group, a market researcher, predicts that revenues from WLAN products will exceed \$2 billion in the year 2002, and show a steady growth of unit shipments and revenues. Demand for computing and telephony mobile devices will be one of the most influential market drivers, along with end users demanding higher data rates and ease of use to sustain growing Internet and data applications.

However, several issues remain unsolved for the industry. Voice and video are increasingly demanding not only faster data rates but also quality of service. Although vendors have made great strides in achieving interoperability, a common wireless standard is far from reality (with over seven standards today). Interference from competing 2.4 GHz technologies, such as Bluetooth and HomeRF, are threatening the overly crowded band. In addition, uncertainties exist with two technologies migrating to the evolving 5 GHz spectrum – one that is leveraging the 802.11b base and is proficient in data applications and the other which is the “new kid on the block” and promises to solve many of the multimedia communication issues.

## Technology (Physical and Data-Link Layers)

WLANs focus on the PHY (physical) layer and the data-link layer (which includes the medium access control and logical link control sub-layers) of the 7-Layer OSI network model. The physical layer defines the electrical, mechanical and procedural specifications, which provides the transmission of bits over a communication medium or channel. WLAN PHY layer technologies used are narrowband radio, infrared, OFDM, and spread spectrum. The MAC layer ensures error control and synchronization between the physically connected devices communicating over a channel. It is also responsible for determining priority and allocation to access the channel.

### PHY Layer (Radio) Technologies

WLANs exist for 900 MHz, 2.4 GHz and 5 GHz ISM (industrial, scientific, medical) bands. While the 2.4 GHz spectrum so the introduction of these products, 5 GHz seems to be the spectrum where mass deployment of WLAN products will initiate. The following PHY layer technologies are popular for WLANs:

#### Infrared (IR)

Infrared technology uses very high frequencies, just below visible light in the electromagnetic spectrum to carry data. While popular with other wireless technologies, it is not gaining momentum with WLANs. IR cannot penetrate opaque objects and uses directed (line-of-sight) technology, and is hence good for small rooms. It is simple, cheap, and unregulated. It is good for inexpensive, directed, very limited range (up to three feet) systems, such as personal area networks.

#### Narrowband Radio

In narrowband radio, the user transmits and receives information on a specific frequency. This RF is kept as low as possible, just enough to be able to pass the information. Any undesirable crosstalk between communication channels is carefully avoided by coordinating the different users on different frequency channels. In a radio system, privacy and non-interference are accomplished by using separate RF. The receiver radio filters out all the radio signals, tuning only to the desired one. This technology requires the end user to obtain a FCC license for each site where this technology is to be deployed.

#### Spread Spectrum (SS)

SS was developed as a wideband RF technology for reliable, secure and mission-critical, military communications while trading off bandwidth. In this modulation technique, the radio transceiver spreads a signal's power over a wider band of frequencies. The spreading process makes the data signal much less susceptible to electrical noise than conventional radio modulation techniques. The transmitted signal occupies a bandwidth considerably greater than the minimum necessary to send the information. Sacrificing processing gain (bandwidth) to gain signal-to-noise performance contradicts the desire to conserve frequency bandwidth. However, the tradeoff produces much louder and easier to detect signals, if the receiver knows the parameters of the broadcast signal. In addition, unless the receiver tunes into the right frequency the SS signal appears as background noise (shown in [Figure 2](#)).

Narrow bandwidth transmission and electrical noises interfere with a small portion of the SS signal and result in much less interference and fewer errors when the receiver demodulates the signal. Some of the SS modulation advantages include low power spectral density, interference limited operation, privacy, and random access possibilities.

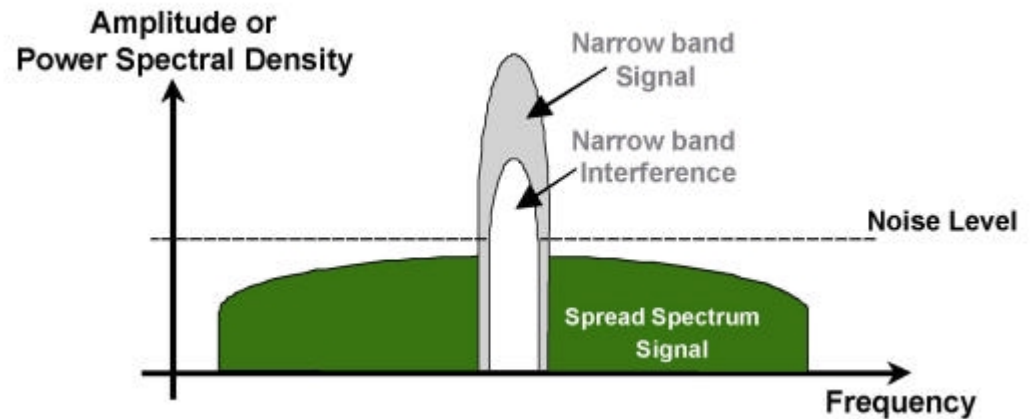


Figure 2: Spread Spectrum Modulation

The two SS modulation techniques include:

- **Frequency Hopping Spread Spectrum (FHSS):** In FHSS, a data signal is modulated with a narrowband carrier signal that hops from frequency-to-frequency as a function of time over a wide band of frequencies. It relies on frequency diversity to combat interference, which is accomplished by multiple frequencies, code selection and FSK. For example, a frequency hopping radio will hop the carrier frequency over the 2.4 GHz frequency band between 2.4 GHz and 2.483 GHz. If the radio encounters interference on one frequency, the radio will retransmit the signal on a subsequent hop on another frequency (shown in [Figures 3 and 4](#)).

The hopping code determines the frequencies the radio will transmit on and in what order. Both the transmitter and receiver know the hopping pattern. To properly receive the signal, the receiver must be set to the same hopping code and listen to the incoming signal at the right time and correct frequency. If properly synchronized the net effect is to maintain a single logical channel. An unintended receiver sees FHSS signals to be short-duration noise impulses. Because of the nature of its modulation technique, frequency hopping can achieve up to 2 Mbps data rates and faster data rates are susceptible to an increased number of errors.

However, the FH technique reduces interference. An interfering signal from a narrowband system will affect the SS signal only if both are transmitting at the same frequency at the same time. It should be noted that this is unlike Frequency Division Multiplexing (FDM), where each channel stays on one frequency slot for the duration of the transmission

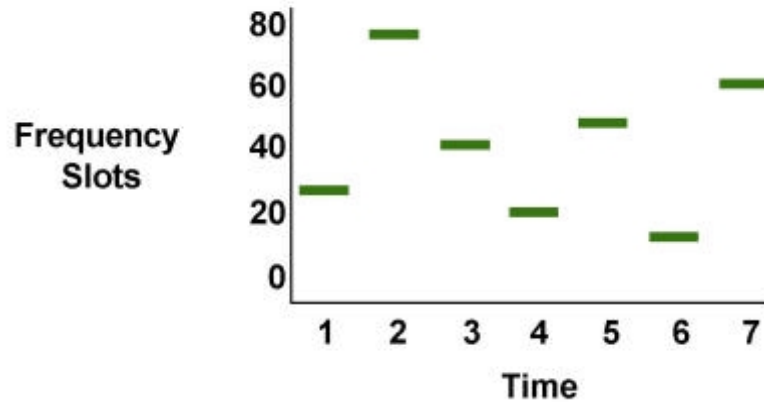


Figure 3: FHSS Frequency Slots

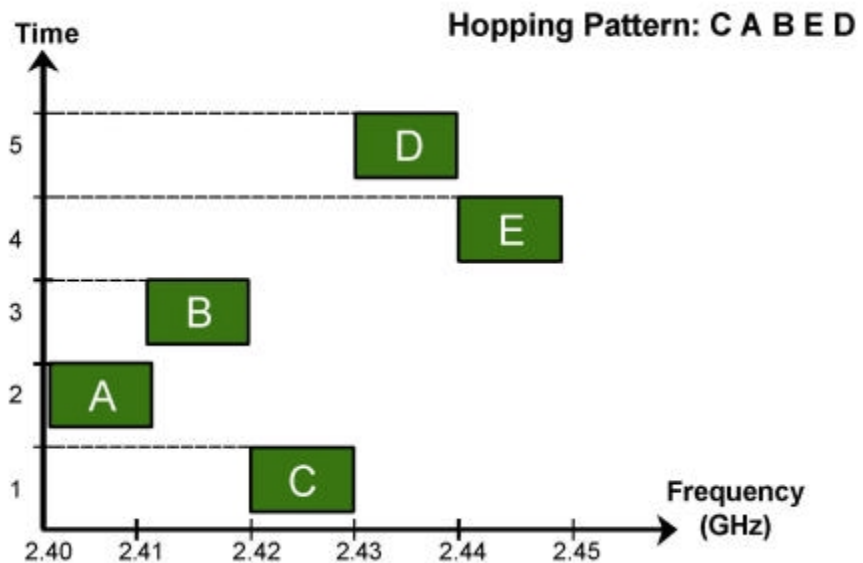


Figure 4: FHSS Hopping Pattern

- Direct Sequence Spread Spectrum (DSSS):** Direct sequence is a more advanced, more recognized and more used form of SS today. The DSSS process is performed by effectively multiplying a RF carrier and a pseudo-noise (PN) digital signal. First, the PN code is modulated onto the information signal using one of several modulation techniques (such as BPSK and QPSK). Then, a doubly balanced mixer is used to multiply the RF carrier and PN modulated information signal. This process causes the RF signal to be replaced with a very wide bandwidth signal with the spectral equivalent of a noise signal.

If seen in the frequency domain, the signals generated by DSSS technique appear to be noise. The wide bandwidth provided by the PN code allows the signal power to drop below the noise threshold without the loss of information. DSSS combines a data signal at the sending station with a higher data bit sequence. The high processing gain increases the signal's resistance to interference.

A chipping code is assigned to represent logic "1" and "0" data bits. As the data stream is transmitted, it is actually the corresponding code that is sent. A 10-chip

code word for each "1" data bit is used. A similar but inverted 10-chip code word is used for the "0" data bit. **Figure 5** shows how DSSS sends a specific string of bits (chipping code) for every data bit sent. DSSS generates redundant bit pattern for each bit to be transmitted. This bit pattern is called chip/chipping code (processing gain). The longer the chip, greater is the probability that the original data will be recovered, but also more bandwidth that is required for transmitting more chips. If one or more bits are damaged during transmission, statistical techniques embedded in the radio can recover the original data without the need for retransmission. The unintended receivers view DSSS as a low-power wideband noise and is ignored or rejected by most narrowband receivers.

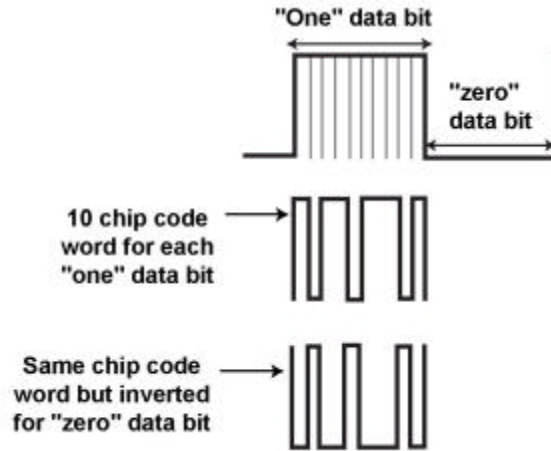


Figure 5: DSSS sends a specific string of bits for each data bit sent

**Figure 6** shows the main differences between the two spread spectrum techniques — frequency hopping and direct sequence.

Direct Sequence (DS)	Frequency Hopping (FH)
Higher Throughput Wider Range	Interference immunity Echo resistant
Upgradeable to higher speeds at 2.4GHz	Less expensive than DS systems Simpler Installation
	More extensive product selection, more vendors

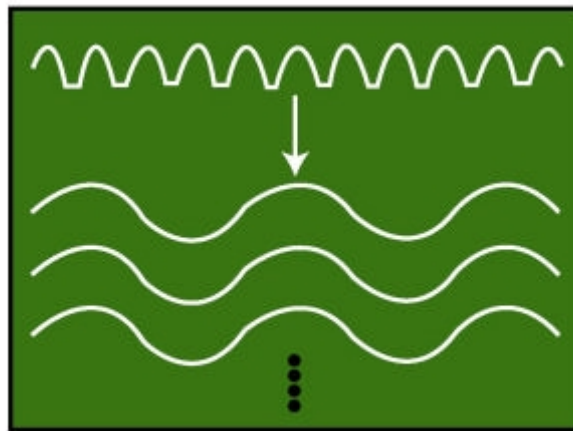
Figure 6: Direct Sequence vs. Frequency Hopping



## Orthogonal Frequency Division Multiplexing (OFDM)

OFDM technology is extremely effective in time-dispersive environments. The signals can take several paths to reach their destinations, thus resulting in variable time delays. At high data rates these time delays can reach a significant proportion of the transmitted symbol (a modulated waveform). This results in one symbol interfering with the next, thus making OFDM the only answer to intersymbol interference.

OFDM is a special method of multi-carrier modulation. Like all wireless transmission schemes, OFDM encodes data onto a RF signal. In OFDM a single high-frequency carrier is replaced by multiple subcarriers, each operates at a significantly lower frequency. Hence, OFDM is the division of a single high-frequency radio channel into multiple subcarriers. The data is transmitted in parallel bit streams on the subcarriers, with each one of these bit streams is modulated on a separate subcarrier (Figure 7). The channel spectrum is passed into a number of independent non-selective frequency sub-channels. These sub-channels are used for one transmission link between the APs and mobile terminals.



*Figure 7: OFDM — Single high-frequency carrier is replaced by multiple subcarriers, each operating at a significantly lower frequency*

The aggregate throughput is the same but the data rate on each subcarrier is much lower. Hence it makes each symbol longer, but practically eliminates the effect of the variable time delays. However, OFDM demands extremely linear power amplifiers, which increases the cost of the radio. OFDM is efficiently realized by using effective signal processing, fast-Fourier transforms (FFT) in the transmitter and receiver. It significantly reduces the amount of hardware required compared to earlier FDM-systems. OFDM requires a properly designed system, and especially important is the design of frequency synchronization and power amplifier back off in the receiver. OFDM results in a very efficient use of bandwidth and provides robust communications in the presence of noise, intentional or unintentional interference, and reflected signals that degrade radio communications. Conventional single-carrier, transmission schemes like AM/FM send only one signal at a time using one RF. Also, lesser utilization of hardware is possible resulting from effective signal processing and FFT. This translates to fewer parts used and savings from lesser EMI testing.

The benefits of OFDM are high spectral efficiency, resiliency to RF interference, and lower multi-path distortion. The orthogonal nature of OFDM allows subchannels to overlap, having a positive effect on spectral efficiency. Each one of the subcarriers

transporting information are just far enough apart from each other to theoretically avoid interference. The parallel form of transmission over multiple subcarriers enables OFDM-based WLANs to operate at higher aggregate data rates, such as 54 Mbps for IEEE 802.11 and HiperLAN2 implementations. In addition, interfering RF signals will only destroy the portion of the OFDM transmitted signal related to the frequency of the interfering signal.

OFDM exhibits lower multi-path distortion (delay spread), since the high-speed composite's sub-signals are sent at lower data rates. Because of the lower data rate transmissions, multipath-based delays are not nearly as significant as they would be with a single channel high-rate system. For example, a narrowband signal sent at a high rate over a single channel will experience greater negative effects from delay spread because the transmitted symbols are closer together. In fact, the information content of a narrowband signal can be completely lost at the receiver if the multipath distortion causes the frequency response to have a null at the transmission frequency. The use of multicarrier OFDM significantly reduces this problem.

Multipath distortion can also cause intersymbol interference, which occurs when one signal overlaps with an adjacent signal. OFDM signals typically have a time guard of 800 ns, however, which provides good performance on channels having delay spreads up to 250 ns. This is good enough for all but the harshest environments. Delay spread due to multipath propagation is generally less than 50 ns in homes, 100 ns in offices and 300 ns in industrial environments.

Many wired and wireless standards bodies have adopted OFDM for a variety of applications. OFDM is the global standard for asymmetric digital subscriber line (ADSL) and for digital audio broadcasting (DAB). In the WLAN space, OFDM will be at the heart of the upcoming IEEE 802.11a and HiperLAN2 technologies. The higher data rates and robust communication of OFDM enables the implementation of WLANs and MANs (Metropolitan Area Networks), supporting higher speed applications and operating over wider areas — hence focussing on point-to-point and point-to-multipoint configurations.

A problem with implementing WLAN products based on OFDM, is the limited range they exhibit because of the high operating frequency combined with the relatively low power. This makes it difficult to maintain acceptable SNRs (signal-to-noise ratios) over longer distances. As a result, a relatively large number of APs are needed to provide enough radio coverage for supporting mobility in local areas. Hence, suppliers of OFDM technology may wait until prices decrease due to economies of scale before releasing OFDM-based WLAN products.

OFDM's high degree of spectral efficiency resiliency to interference and multipath distortion, and existing inclusions in the leading higher rate WLAN standards, provides a strong base for the development of newer broadband wireless networks. The technology is certainly proven; however, the unknown future unification of a single standard (of IEEE 802.11a and HiperLAN2) is causing some grief among those deciding which version of OFDM to implement in their products. In addition, the non-conformance to a single standard is hampering the benefits of economies of scale as companies utilize dissimilar components based on their chosen version of OFDM. Regardless, the future for OFDM is bright as it gains significant momentum in the industry.



## Data-Link Layer Technologies

The data-link layer is the second layer in the OSI model, and it performs the assembly and transmission of data packets (gets data packets on and off the wire), does error detection and correction, synchronization and retransmission. The data-link layer is divided into the following two sub-layers:

- **Logical Link Control (LLC) Sub-layer:** The LLC sub-layer resides above the MAC sub-layer in the data link layer. It is responsible for the framing (or frame construction). The LLC inserts certain fields in the frame such as source and destination address at the head end of the frame and error handling bits at the end of the frame.
- **Media Access Control (MAC) Sub-layer:** The MAC provides access control functions for shared medium PHYs in support of the LLC layer. The primary functions of the MAC layer include addressing (accessing the wireless medium), access coordination (joining the network) and frame check sequence generation and checking (providing authentication and privacy).

The MAC layer for WLANs use access protocols such as carrier sense multiple access (CSMA) and time division multiple access (TDMA). These technologies are explained in some detail below:

### Carrier Sense Multiple Access (CSMA)

It is a network access method where two or more stations share a common transmission medium. CSMA/CD (Carrier Sense Multiple Access with Collision Detection) is used by Ethernet technology in which a station listens for traffic before transmitting. If two stations transmit simultaneously, a collision is detected and both stations wait a brief time before attempting to transmit again. It is so called because it allows multiple stations to access the broadcast channel at will, avoids contention via carrier sense and deference, and resolves contention via collision detection and retransmission. The algorithm is shown in [Figure 8](#).

CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) is a modified version of the CSMA/CD access technique. Each of the hardware devices attached to the talkers on the network estimates when a collision is likely to occur and avoids transmission during those times. Since this technique eliminates the requirement for collision-detection hardware, the cost of hardware to implement this access technique is usually less than that of CSMA/CD hardware. CSMA and its variations are ideal for data networks, and are used in small, high-speed, data-centric environments such as LANs.

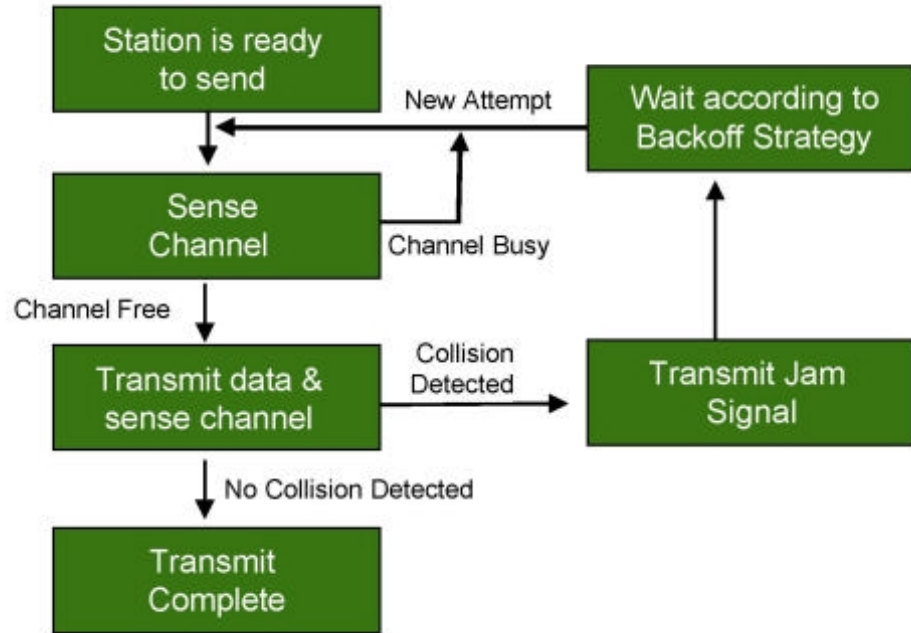


Figure 8: CSMA/CA Algorithm

### Time Division Multiple Access (TDMA)

TDMA is digital transmission technology that allows a number of users to access a single radio-frequency (RF) channel without interference by allocating unique time slots to each user within each channel. The TDMA digital transmission scheme multiplexes three signals over a single channel. TDMA relies upon the fact that the audio (or other data) signal has been digitized; that is, divided into a number of milliseconds-long packets. It allocates a single frequency channel for a short time and then moves to another channel. The digital samples from a single transmitter occupy different time slots in several bands at the same time.

The time is divided amongst transmitters, who transmit only on their allotted time slot. It can be easily adapted to the transmission of data as well as voice communication, and is hence ideal technology for interactive voice and personal communication-like services including fax, data, and short message services as well as bandwidth-intensive applications such as multimedia and videoconferencing. However, due to predefined time slots there is a lot of wasted bandwidth when communication is not in progress. Another problem with TDMA is that it is subjected to multipath distortion.

Some of the popular WLAN technologies are IEEE 802.11a, IEEE 802.11b and HiperLAN2.

## IEEE 802.11 Family of Standards

In 1997, the IEEE finalized the initial standard for WLANs, IEEE 802.11. This standard specified a 2.4 GHz operating frequency with data rates of 1 and 2 Mbps using either DSSS or FHSS.

The IEEE 802.11 working group has since published two variations to the 802.11 standard — the IEEE 802.11b and IEEE 802.11a. When the IEEE ratified the 802.11a and 802.11b wireless networking communications standards in 1999, its goal was to create a standards-based technology that could span multiple physical encoding types, frequencies and applications in the same way the 802.3 Ethernet standard has been successfully applied to 10 Mbps, 100 Mbps and 1 Gbps technology over fiber and copper. The 802.11a standard, which supports data rates of up to 54 Mbps, is the Fast Ethernet analog to 802.11b, which supports data rates of up to 11Mbps. Like Ethernet and Fast Ethernet, 802.11b and 802.11a use an identical MAC. However, while Fast Ethernet uses the same PHY encoding scheme as Ethernet (only faster), 802.11a uses an entirely different encoding scheme, called OFDM.

### IEEE 802.11b

The IEEE 802.11b extension employs a modulation scheme called complementary code keying (CCK) and operates in the 2.4 GHz ISM band. It is designed to enable data rates of 1 to 2 Mbps for FHSS networks and 1 to 11 Mbps for DSSS systems and provide interoperability between both DSSS and FHSS networks. The MAC uses the CSMA/CA technique.

The WECA (Wireless Ethernet Compatibility Alliance) consortium supports this 2.4 GHz DSSS technology. Products that pass the WECA test are stamped with a WECA seal of approval, called "WiFi" (pronounced Y-Phi) for "wireless fidelity". The WECA stamp helps consumers identify products that are interoperable, thus helping the sale of 802.11b products. These products are very popular in the SOHO and enterprise space, and several products based on 802.11b are being introduced in the home market as well.

### IEEE 802.11a

IEEE 802.11a, a recently formalized extension to the 802.11 family, provides higher speeds (6 to 54 Mbps) and compatibility with existing standards. IEEE 802.11a utilizes the more recently allocated 5 GHz UNII (Unlicensed National Information Infrastructure) band for the PHY layer. And unlike 802.11b, the 802.11a standard departs from the traditional spread-spectrum technology, and instead uses the frequency division-multiplexing scheme, known as OFDM. This move was because OFDM is intended to be friendlier to office environments.

The 802.11a standard is designed to operate in the 5 GHz frequency range. Specifically, the FCC has allocated 300MHz of spectrum for unlicensed operation in the 5 GHz block, 200 MHz of which is at 5.15 GHz to 5.35 GHz, with the other 100 MHz at 5.725 GHz to 5.825 GHz. The spectrum is split into three working "domains." The first 100MHz in the lower section is restricted to a maximum power output of 50 mW (milliwatts). The second 100 MHz has a more generous 250 mW power budget, while the top 100 MHz is delegated for outdoor applications, with a maximum of 1W power output. In contrast, 802.11b cards can radiate as much as 1W in the United States. However, most modern cards radiate only a fraction (30 mW) of the maximum available power for reasons of battery conservation and heat dissipation.

Although segmented, the total bandwidth available for IEEE 802.11a applications is nearly four times that of the (2.4 GHz) ISM band; the ISM band offers only 83 MHz of spectrum in the 2.4 GHz range, while the newly allocated UNII band offers 300 MHz.

The 802.11b spectrum is plagued by saturation from wireless phones, microwave ovens and other emerging wireless technologies, such as Bluetooth and HomeRF. In contrast, the 802.11a spectrum is relatively free of interference, with HiperLAN2 being the only other technology that shares its spectrum.

The 802.11a standard gains some of its performance from the higher frequencies at which it operates. The laws of information theory tie frequency, radiated power and distance together in an inverse relationship. Thus, moving up to the 5 GHz spectrum from 2.4 GHz will lead to shorter distances, given the same radiated power and encoding scheme. In addition, the encoding mechanism used to convert data into analog radio waves can encode one or more bits per radio cycle (Hertz). By rotating and manipulating the radio signal, vendors can encode more information in the same time slice. To ensure that the remote host can decode these more complex radio signals, you must use more power at the source to compensate for signal distortion and fade. The 802.11a technology overcomes some of the distance loss by increasing the power to the maximum 50 mW.

However, power alone is not enough to maintain 802.11b-like distances in an 802.11a environment. To compensate, 802.11a uses OFDM as the PHY encoding technology. OFDM was developed specifically for indoor wireless use and offers performance much superior to that of spread-spectrum solutions. OFDM works by breaking one high-speed data carrier into several lower-speed subcarriers, which are then transmitted in parallel. Each high-speed carrier is 20 MHz wide and is broken up into 52 subchannels, each approximately 300 KHz wide. OFDM uses four of these subchannels as pilot subcarriers that the system uses as a reference to disregard frequency or phase shifts of the signal during transmission and are used for error correction. A pseudo binary sequence is sent through the pilot subchannels to prevent the generation of spectral lines. The remaining 48 subcarriers provide separate wireless pathways for sending the information in a parallel fashion. The resulting subcarrier frequency spacing is 0.312 5MHz (for a 20 MHz with 64 possible sub-carrier frequency slots). The primary purpose of the OFDM PHY is to transmit the MAC protocol data units (MPDUs) as directed by the 802.11 MAC layer.

OFDM delivers higher data rates and a high degree of multipath reflection recovery, thanks to its encoding scheme and error correction. The 802.11a version of OFDM uses a combination of binary phase shift keying (BPSK), quadrature PSK (QPSK), and quadrature amplitude modulation (QAM), depending on the chosen data rate. The PHY preamble and signal field is convolutionally encoded and sent at 6 Mbps using BPSK no matter what data rate the signal field indicates. The convolutional encoding rate depends on the chosen data rate. With 802.11a OFDM modulation, the binary serial signal is divided into groups (symbols) of one, two, four, or six bits, depending on the data rate chosen, and converted into complex numbers representing applicable constellation points. If a data rate of 24 Mbps is chosen, for example, then the PHY maps the data bits to a 16-QAM constellation (encoding four bits per Hertz).

Each sub-channel in the OFDM implementation is about 300 KHz wide. At the low end of the speed gradient, BPSK is used to encode 125 Kbps of data per channel, resulting in a 6Mbps data rate. Using quadrature phase shift keying, one can double the amount of data encoded to 250 Kbps per channel, yielding a 12 Mbps data rate. The 802.11a standard specifies that all 802.11a-compliant products must support these basic data rates. The standard also lets the vendor extend the modulation scheme beyond 24 Mbps. The more bits per cycle (Hertz) that are encoded, the more susceptible the signal will be to interference and fading, and ultimately, the shorter the range, unless power output is increased.

The de facto standard for 802.11a networking appears to be 54 Mbps. Data rates of 54 Mbps are achieved by using 64QAM (64-level), which yields eight bits per cycle or ten bits per cycle, for a total of up to 1.125 Mbps per 300 KHz channel. With 48 channels, this results in a 54 Mbps data rate. The PHY splits the information signal across 52 separate subcarriers to provide transmission of data at a rate of 6, 9, 12, 18, 24, 36, 48, or 54 Mbps. The 6, 12 and 24 Mbps data rates are mandatory for all products. IEEE 802.11a uses CSMA/CA algorithm for its MAC layer, similar to IEEE 802.11b. CSMA protocol targets asynchronous traffic such as client-server applications. It lacks QoS (quality of service) support, which is essential for voice and video applications. The use of CSMA proves that the attempt of 802.11a is to provide data faster, much like Fast Ethernet did with Ethernet. However, QoS still remains unsolved, which begs the question of multimedia and how 802.11a plans to tackle networking in the home, SOHO, enterprise and public area environments.

## HiperLAN2 Technology

HiperLAN2, a next generation global WLAN technology, takes advantage of the latest developments in radio technology, MAC protocol for high efficiency, quality of service (QoS), radio resource management, power savings and plug-and-play. The ETSI (European Telecommunications Standards Institute) started the BRAN (Broadband Radio Access network) project to develop HiperLAN2. HiperLAN2 specification embodies the PHY and MAC components. The HiperLAN2 Global Forum develops, markets, and supports this technology.

HiperLAN2 is an OFDM-based, variable bit rate PHY layer technology operating at 5 GHz. While the PHY is very similar to the 802.11a PHY (with varying convolutional codes), it has FEC error control, with dynamic sub-channel modulation allowing data transmission at higher rates with a strong SNR at lower throughputs in adverse conditions. HiperLAN2 provides high bandwidth up to 54 Mbps, with a range of over 150 meters. It has a generic architecture and supports Ethernet, IEEE 1394, ATM, PPP, 3G. The HiperLAN2 data-link layer/MAC provides QoS via dynamic fixed time slots. The time slotted structure allows simultaneous communication in both downlink and up-link in the same period. It is also a connection-oriented technology that allows negotiation of QoS parameters like bandwidth, bit error rate, latency, jitter, and delay requirements. This assures that other terminals will not interfere with subsequent transmissions. It provides ARQ (Automatic Repeat reQuest), dynamic frequency selection, power control and power save, cellular hand-over, and security (authentication and encryption).

HiperLAN2 provides connections, which can be assigned a specific QoS over the air between the terminal and the base station. Whilst moving, HiperLAN2 automatically performs handover to the nearest base station (or AP). HiperLAN2 also has a strong security support with built-in facility for automatic frequency allocation, removing the need for manual frequency planning. HiperLAN2 offers high-speed wireless connectivity and seamless connectivity with corporate LAN, 3G cellular systems, mobility, and QoS for future applications such as multimedia, voice over Internet protocol (VoIP) and real-time video.

## Key Features

Some of the features and a short description are described below:

- **High-Speed Transmission:** HiperLAN2 has a very high transmission rate, which at the physical layer extends up to 54 Mbps, and on layer 3 up to 25 Mbps. To achieve this, HiperLAN2 makes use of OFDM modulation to transmit the analog signals. OFDM is very efficient in time-dispersive environments, e.g., within



offices, where the transmitted radio signals are reflected from many points, leading to different propagation times before they eventually reach the receiver. Above the physical layer, the MAC protocol is completely new which implements a form of dynamic time-division duplex to allow for most efficient utilization of radio resources.

- **Connection-Oriented:** In a HiperLAN2 network, data is transmitted on connections between the MT and the AP that have been established prior to the transmission using signaling functions of the HiperLAN2 control plane. Connections are time-division-multiplexed over the air interface. There are two types of connections, point-to-point and point-to-multipoint. Point-to-point connections are bi-directional whereas point-to-multipoint are unidirectional in the direction towards the MT. There is also a dedicated broadcast channel through which traffic reaches all terminals transmitted from one AP.
- **QoS Support:** The connection-oriented nature of HiperLAN2 makes it straightforward to implement support for QoS. Each connection can be assigned a specific QoS, for instance in terms of bandwidth, delay, jitter, bit error rate, etc. It is also possible to use a more simplistic approach, where each connection can be assigned a priority level relative to other connections. This QoS support in combination with the high transmission rate facilitates the simultaneous transmission of many different data streams, i.e., video, voice, and data.
- **Automatic Frequency Allocation:** In a HiperLAN2 network, there is no need for manual frequency planning as in cellular networks like GSM. The radio base stations, i.e., APs in HiperLAN2, have built-in support for automatically selecting an appropriate radio channel for transmission within each AP's coverage area. An AP listens to neighboring APs as well as to other radio sources in the environment, and selects an appropriate radio channel based on both what radio channels are already in use by those other APs and to minimize interference with the environment.
- **Security Support:** The HiperLAN2 network has support for both authentication and encryption. With authentication, both the AP and the MT can authenticate each other to ensure authorized access to the network (from the AP) or to ensure access to a valid network operator (from the MT). Authentication relies on the existence of a supporting function, such as a directory service, but which is outside the scope of HiperLAN2. The user traffic on established connections can be encrypted to protect against for instance eavesdropping and man-in-middle attacks.
- **Mobility Support:** The MT transmits and receives data to/from the "nearest" AP, or more correctly speaking the MT uses the AP with the best radio signal as measured by the signal to noise ratio. Thus, as the user and the MT move around, the MT may detect that there is an alternative AP with better radio transmission performance than the AP, which the MT is currently associated to. The MT will then order a hand over to this AP. All established connections will be moved to this new AP resulting in that the MT stays associated to the HiperLAN2 network and can continue its communication. During handover, some packet loss may occur. If an MT moves out of radio coverage for a certain time, the MT may lose its association to the HiperLAN2 network resulting in the release of all connections.
- **Network and Application Independent:** The HiperLAN2 protocol stack has a flexible architecture for easy adaptation and integration with a variety of fixed networks. A HiperLAN2 network can for instance be used as the "last hop" wireless segment of a switched Ethernet, but it may also be used in other



configurations, e.g., as an access network to third generation cellular networks. All applications, which today run over fixed infrastructure, can also run over a HiperLAN2 network.

- **Power Save:** In HiperLAN2, the mechanism to allow for a MT to save power is based on MT-initiated negotiation of sleep periods. The MT may at any time request the AP to enter a low power state and requests for a specific sleep period. At the expiration of the negotiated sleep period, the MT searches for the presence of any wake up indication from the AP. In the absence of the wake up indication the MT reverts back to its low power state for the next sleep period, and so forth. An AP will defer any pending data to a MT until the corresponding sleep period expires. Different sleep periods are supported to allow for either short latency requirement or low power requirement.

## End Applications

HiperLAN2 is targeted at the following applications:

- **Office/Enterprise/Corporate LAN:** In a corporate network built around Ethernet LAN and IP routers, a HiperLAN2 network is used as the last segment between the MTs and the network/LAN. The HiperLAN2 network supports mobility within the same LAN/sub-net.
- **Construction:** With HiperLAN2 installed, workers on a construction site can use laptops to collect blue prints, order materials and communicate with experts.
- **Home Network:** Domestic electronics like televisions, stereo equipment, PCs and more can all be interconnected/networked by HiperLAN2 using small H2 modules which automatically establish connectivity. HiperLAN2 allows the creation of a wireless infrastructure for home devices and multimedia equipment to be intelligently controlled from any computing device in the home without the need for network cables. The high throughput and QoS features of HiperLAN2 support the transmission of video streams in conjunction with the datacom applications. The AP may in this case include an “uplink” to the public network, e.g., an ADSL or cable modem
- **Public Hot Spots:** HiperLAN2 networks can be deployed at hot spot areas, e.g., airports, hotels, coffee shops, etc, to enable an easy way of offering remote access and Internet services to business people. An access server to which the HiperLAN2 network is connected can route a connection request for a point-to-point connection (PPP) over a tunnel either to the corporate network (via a preferred ISP) for Internet access.
- **University:** HiperLAN2 benefits both students and lecturers, allowing wireless access to the university and the Internet. Covering the entire campus, students can access information, such as videotaped lectures and remote supervision transmitted by their lecturer and two-way communication can take place between students and lecturers through laptops.
- **Access to Third Generation Cellular Network:** HiperLAN2 can be used as an alternative access technology to a 3G cellular networks, to cover hot spots and city areas with HiperLAN2 and the wide area with W-CDMA technology. In this way, a user can benefit from a high-performance network wherever it is feasible to deploy HiperLAN2 and use W-CDMA elsewhere. The core network sees to that the user is automatically and seamlessly handed over between the two types of access networks as the user moves between them.

## Protocol Architecture

The HiperLAN2 protocol is divided into three basic layers:

- **Physical layer:** The transmission format on the physical layer is a burst, which consists of a preamble part and a data part, where the latter could originate from each of the transport channels within DLC. Orthogonal Frequency Division Multiplexing (OFDM) has been chosen due to its excellent performance on highly dispersive channels. The channel spacing is 20 MHz, which allows high bit rates per channel but still has a reasonable number of channels in the allocated spectrum (19 channels in Europe). 52 subcarriers are used per channel, where 48 subcarriers carry actual data and four subcarriers are pilots, which facilitate phase tracking for coherent demodulation.

OFDM is a special form of multicarrier modulation that transmits broadband, high data rate information by dividing the data into several interleaved, parallel bit streams, and let each one of these bit streams modulate a separate subcarrier. In this way the channel spectrum is passed into a number of independent non-selective frequency sub channels. These subchannels are used for one transmission link between the AP and the MTs. OFDM is efficiently realized by the use of effective signal processing, fast-fourier transform, in the transmitter and receiver. This significantly reduces the amount of required hardware compared to earlier FDM-systems. One of the benefits of OFDM is the robustness against the adverse effects of multipath propagation with respect to intersymbol interference. It is also spectrally efficient because the subcarriers are packed maximally close together. OFDM also admits great flexibility considering the choice of and realization of different modulation alternatives. As a key feature of the physical layer is to provide several modulation and coding alternatives, OFDM provides both to adapt to current radio link quality and to meet the requirements for different physical layer properties as defined for the transport channels within DLC.

- **Data Link Control (DLC) Layer:** The DLC constitutes the logical link between an AP and the MTs, and includes functions for both medium access and transmission (user plane) as well as terminal/user and connection handling. The DLC consists of a set of sub-layers:
  - *Medium Access Control (MAC):* The MAC is used to access the medium (the radio link) with the resulting transmission of data onto that medium. The control is centralized to the AP which inform the MTs at which point in time in the MAC frame they are allowed to transmit their data, which adapts according to the request for resources from each of the MTs. The air interface is based on time-division duplex (TDD) and dynamic time-division multiple access (TDMA), i.e., the time-slotted structure of the medium allows for simultaneous communication in both downlink and uplink within the same time frame, called MAC frame in HiperLAN2. Time Division Duplexing is a duplexing technique dividing a radio channel in time to allow downlink operation during part of the frame period and uplink operation in the remainder of the frame period. In TDMA, the frequency band is split into a number of channels, which in turn are stacked into short time units, so that several calls can share a single channel without interfering with one another. Networks using TDMA assign six timeslots for each frequency channel. Time slots for downlink and uplink communication are allocated dynamically depending on the need for transmission resources. The basic HiperLAN2 MAC frame structure on the air interface has a fixed duration of 2 ms and comprises transport channels for broadcast control, frame control, access

control, downlink and uplink data transmission and random access. All data from both AP and the MTs is transmitted in dedicated time slots, except for the random access channel where contention for the same time slot is allowed. The duration of broadcast control is fixed whereas the duration of other fields is dynamically adapted to the current traffic situation. The MAC frame and the transport channels form the interface between DLC and the physical layer. The HiperLAN2 MAC also provides explicit support for the use of “smart” sectorized antennas at the AP.

- *Error Control (EC)*: Selective Repeat (SR) ARQ is the EC mechanism that is used to increase the reliability over the radio link. EC in this context means detection of bit errors and the resulting retransmission of U-PDU(s) if such errors occur. EC also ensures that the U-PDUs are delivered in-sequence to the convergence layer.
- *Radio Link Control (RLC) protocol*: The RLC protocol gives a transport service for the signaling entities Association Control Function (ACF), Radio Resource Control function (RRC), and the DLC user Connection Control (DCC) function. These four entities comprise the DLC control plane for the exchange of signaling messages between the AP and the MT.
- **Convergence Layer (CL)**: The CL has two main functions - adapting service request from higher layers to the service offered by the DLC and to convert the higher layer packets (SDUs) with variable or possibly fixed size into a fixed size that is used within the DLC. The padding, segmentation and reassembly function of the fixed size DLC SDUs is one key issue that makes it possible to standardize and implement a DLC and PHY that is independent of the fixed network to which the HiperLAN2 network is connected. The generic architecture of the CL makes HiperLAN2 suitable as a radio access network for a diversity of fixed networks, e.g. Ethernet, IP, ATM, UMTS, etc. There are currently two different types of CLs defined; cell-based and packet-based. The former is intended for interconnection to ATM networks, whereas the latter can be used in a variety of configurations depending on fixed network type and how the interworking is specified. The structure of the packet-based CL with a common and service-specific part allows for easy adaptation to different configurations and fixed networks. From the beginning though, the HiperLAN2 standard specifies the common part and a service specific part for interworking with a fixed Ethernet network.

Figure 9 shows the HiperLAN2 protocol structure.

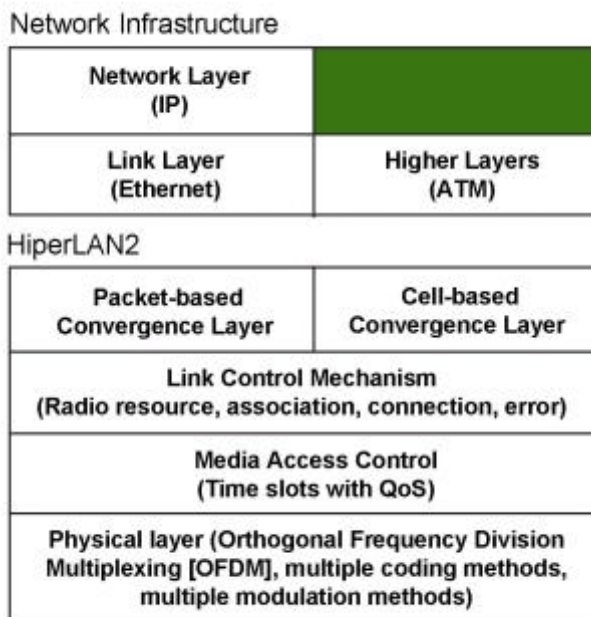


Figure 9: **HiperLAN2 Protocol**

The high data rates and QoS support are more than sufficient to scale to the need of present and future home networking traffic such as multiple streaming MP3 audio and voice-over-IP (VoIP) telephony, Internet access, digital TV, MPEG-2 DVD streams, and even MPEG-4 video on demand (VoD) services. It is also ideal for isochronous applications for public areas, enterprises and SOHOs. HiperLAN2 meets the most important requirements of isochronous traffic, which are guaranteed constant bit rate channel allocations, delay and jitter (delay variation).

## Different WLAN Technologies

Figure 10 shows a table that differentiates the characteristics of the three popular WLAN technologies.

Characteristic	IEEE 802.11b	IEEE 802.11a	HiperLAN2
Spectrum	2.4 GHz	5 GHz	5 GHz
Maximum physical rate	11 Mbps	54 Mbps	54 Mbps
Max. data rate, layer 3	5 Mbps	28 Mbps	32 Mbps
PHY	DSSS (Direct Sequence Spread Spectrum)	OFDM	OFDM (Orthogonal Frequency Division Multiplexing)
Medium access control	CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance)	CSMA/CA	Central resource control/TDMA/TDD (Time Division Multiple Access/Time Division Duplexing)
Connectivity	Connection-less	Connection-less	Connection-oriented
Multicast	Yes	Yes	Yes
QoS support	PCF	PCF	ATM/802.1p/RSVP/DiffServ (full control)
Frequency selection	DSSS	Single carrier	Single carrier with Dynamic Frequency Selection
Authentication	No	No	NAI/IEEE address/X.509
Encryption	40-bit RC4	40-bit RC4	DES, Triple-DES
Handover support	No	No	No
Fixed network support	Ethernet	Ethernet	Ethernet, IP, ATM, UMTS, FireWire (1394), PPP
Management	802.11 MIB	802.11 MIB	HiperLAN/2 MIB
Radio link quality control	No	No	Link adaptation
Organization	IEEE, WECA	IEEE, WECA	HiperLAN2 Global Forum (H2GF)

Figure 10: IEEE 802.11 vs. HiperLAN2

## The Over Utilized 2.4 GHz Band

Today's wireless local area and personal area networks (such as Bluetooth and IEEE 802.15) operate primarily in the 2.4 GHz spectrum, using separate protocols or standards for different applications. In addition, many new cordless telephones, microwave ovens, HomeRF (home networking technology) and baby monitors use this spectrum. These solutions operate independently, all competing for the same 85 MHz of radio spectrum using incompatible protocols — which can often lead to interference, reduced performance and dissatisfied users.

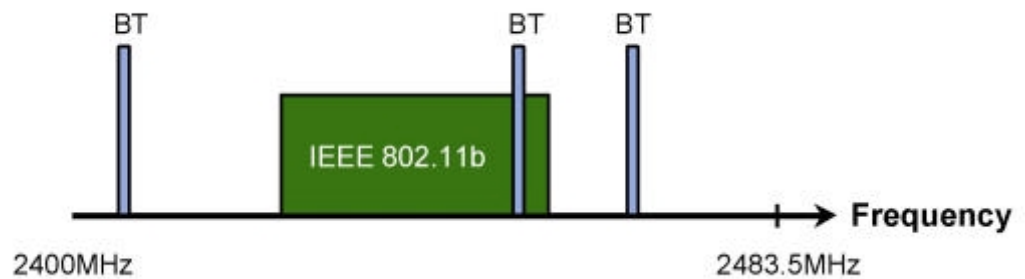
Since the WLAN and WPAN (wireless PANs) devices are likely to be in close proximity to one another and also operate in the same 2.4 to 2.4835 GHz unlicensed ISM spectrum, there is an opportunity for the two systems to interfere with one another. Let's take a closer look at the coexistence between IEEE 802.11b and Bluetooth standards since they are the most popular WLAN and WPAN technologies. As a note, HomeRF also uses FHSS technology in the 2.4 GHz spectrum and through this example one can see the amplified congestion in the 2.4 GHz space.

IEEE 802.11b occupies 22 MHz of bandwidth within the ISM band. The data is spread using a pseudo-random chipping sequence so that the bandwidth stays at 22 MHz, even if the data rate is lowered from 11 Mbps to one of the lower data rates (5.5, 2, and 1 Mbps). Bluetooth hops over the 79 channels, each 1MHz wide, at a rate of 1,600 hops per second. Every time a Bluetooth Piconet hops into the 802.11b frequency band, there is a potential for mutual interference.

Since these two wireless networks occupy the same 2.4 GHz ISM band, as Bluetooth hops around the band, there are some instances when a Bluetooth system and IEEE 802.11/802.11b system may overlap in the frequency domain (Figure 11). This overlap



can cause the systems to interfere with each other, greatly degrading performance in both systems.



*Figure 11: Bluetooth and IEEE 802.11b Systems Operating Together in the 2.4 GHz ISM Band*

In IEEE 802.11b products, the DSSS mechanism works by first multiplying the narrowband message by a larger bandwidth signal, which is usually a pseudorandom noise (PN) code, before being sent by the transmitter. This broadens the spectrum. The amount of broadening is commonly referred to as the process gain and is defined as the ratio of the transmitted bandwidth after the data is spread to the bandwidth of the actual information. Usually the processing gain is much larger than unity.

This broadening technique can be used to allow the development of multi-access systems. In such systems, each user's transmission would be spread with a different PN code and sent within the same frequency band. When the desired spread signal is received, it is multiplied by the appropriate PN code again. This process causes the desired received signal to be despread back to the original transmitted data while all other signals and noise, which are uncorrelated to the PN spreading code used, become more spread. The desired signal is then filtered to remove the remaining wide spread interference and noise signals. In this manner, each user's signal can be independently sent and received in the presence of other users' signals within the same frequency band.

Unfortunately, the IEEE 802.11b DSSS standard, as defined, cannot employ DSSS for multi-access. In short, the required processing gain and bit energy to noise ratio ( $E_b/N_0$ ) do not allow another signal of the same strength (but with different PN code) to be transmitted at the same time. The IEEE 802.11b DS systems can only tolerate interference up to  $-3$  dB relative to the desired signal, which is much less than the interference that can be presented to one user by another on the same channel.

Thus, DSSS technology cannot be used to allow simultaneous transmissions in the same frequency band. It is for this reason that the 802.11b standard segregates simultaneous transmissions onto three different frequencies, each of 22 MHz bandwidth, in order to allow them to transmit at the same time in the allotted 2.4 GHz band.

FHSS systems, such as Bluetooth and HomeRF devices, differ from DSSS systems in the manner they try to avoid interference. FHSS systems avoid interference with other transmission signals in the same band by hopping over many different frequency channels. During any one hop, an FHSS signal appears to be in a narrowband signal. In the case of Bluetooth, for example, this narrowband signal has a 1 MHz bandwidth and hops 1,600 times per second over 79 channels. Therefore, an FHSS signal is agile and does not spend much time in any one frequency.



## Performance Challenge

One of the main challenges with FHSS systems is data rate performance. In their current states, FHSS systems can employ 1 MHz narrowband signals that deliver data rates up to 2 Mbps. With the passage of a new rule by the FCC, system designers can increase signal bandwidth to 5 MHz, allowing systems to achieve data rates of up to 10 Mbps. But getting beyond 10 Mbps is not an easy task for FHSS systems, which could limit their performance capabilities in the home-networking environment.

Another key problem with both FHSS and DSSS is interference. Now that FHSS radios can operate at wider bandwidths, there is a clear concern in the industry that more interference may occur between DSSS and FHSS products.

To evaluate the simultaneous interference between DSSS systems such as IEEE 802.11b and FHSS systems such as Bluetooth, it is best to separately examine the effect of each system on the other.

In terms of the interference of narrowband FHSS systems on DSSS transmission, the interference level is severe — especially in the presence of a fast moving signal such as Bluetooth. In terms of the interference of broadband DSSS systems on FHSS transmissions, the effect is still significant. When FHSS systems hit a frequency that has interference, the signal can hop to another channel that is outside the bandwidth of the DSSS system. However, regardless of the scenario, the throughput is almost always reduced.

There are many factors that effect whether there is interference during that time slot. Some of these more common causes include the location of the 802.11 and Bluetooth devices, the power levels of the 802.11 and Bluetooth systems, the data rate of the 802.11 system, and the statistics of the data traffic flowing over both the 802.11 and Bluetooth networks. The user also has to select the type of data traffic flowing over each of the two wireless networks. For example, an 802.11b station may be downloading a file from the AP and the Bluetooth Piconet may have an active voice link. The co-existence model will include a set of typical data traffic models.

There are two types of potential co-existence mechanisms: collaborative and non-collaborative mechanisms. If it is possible for the WPAN and the WLAN to exchange information between one another, then it is possible to develop a collaborative co-existence mechanism, where the two wireless networks negotiate a mechanism to minimize mutual interference. If there is no method to exchange information between the two wireless networks, then a non-collaborative co-existence mechanism is required. Depending on the operating environment one technique may be preferred over the other.

If, for example, Bluetooth and 802.11 are incorporated into the same laptop computer, then it may be possible for the two devices to exchange information, and, as a result, negotiate a collaborative co-existence mechanism. This may be very important in such a scenario since the power level of an interferer can be quite high if the two radios are incorporated into the same laptop. If an IEEE 802.11b WLAN card is installed into a laptop computer and there is a nearby Bluetooth-enabled PDA, which has no connection to the 802.11 laptop, then a non-collaborative mechanism would need to be used.

With the heightened awareness of the need for co-existence, there is a push to consider co-existence up front, when the new standards in the 5 GHz spectrum are being developed.

## The 5 GHz Technology Duel – HiperLAN2 vs. IEEE 802.11a

Because of the overpopulated 2.4 GHz spectrum, next generation WLAN technologies are migrating into the 5 GHz band. This migration is ideal for next-generation WLAN for several reasons:

- Regulatory bodies in the US and Europe have allocated a much broader 200 MHz radio spectrum, enabling higher data throughput.
- The spectrum receives minimal interference from microwave ovens.
- It does not require a license throughout much of the world.
- Because the 5 GHz frequency spectrum is fairly new, no new applications exist for this space.

Developing technologies for the 5 GHz spectrum will enable a single network to support both multimedia and voice traffic on a unified network. It will allow applications such as high-bandwidth Internet, voice, video-on-demand, automated meter reading, telemedicine, and home networking become a reality. However, there are two competing technologies vying to succeed in the 5 GHz spectrum.

Both the IEEE 802.11a and HiperLAN2 specifications operate in the 5 GHz band — specifically 5.15 to 5.35 GHz band. In both technologies the allocated radio spectrum is divided into eight separate network segments or channels of 20 MHz. Each channel supports a certain number of devices, and individual devices can roam across network segments just as a mobile phone gets handed from one base station to another as the user drives around. This 20 MHz spectrum for a network segment support 54 Mbps of data throughput, shared among the devices on the segment at any given time. Within a channel, the 20 MHz spectrum is divided into 52 “narrowband carriers” – each about 300 KHz, based on OFDM technology. The existing specifications allow only one device on the network segment to communicate at a time, using all 52 carriers. From a PHY perspective, both technologies implement OFDM in a similar fashion, and differ only in the way they perform convolutional encoding.

In Europe, the HiperLAN2 standard has gained wide acceptance as the 5 GHz technology of choice. However, that is not the case in the US and Asia. HiperLAN2 and 802.11a share some similarities at the physical layer: Both use OFDM technology to achieve their data rates. However, HiperLAN2 is much more akin to ATM than to Ethernet. In fact, the HiperLAN2 standard grew out of the effort to develop wireless ATM. HiperLAN2 shares the 20 MHz channels in the 5 GHz spectrum in time, using TDMA to provide QoS through ATM-like mechanisms.

In contrast, 802.11a shares the 20MHz channel in time using CSMA/CA. HiperLAN2 uses a different MAC, which is based on TDMA/TDD. The HiperLAN2 MAC design has proven to be problematic and controversial, and the HiperLAN2 standard is still incomplete. In contrast, 802.11a uses the same MAC as 802.11b, which gives developers only one task to complete: a 5 GHz IEEE 802.11a-compliant radio. No simple task, but easier than redesigning the radio and the MAC controller.

In addition, the 802.11a technology will not be readily accepted overseas as certain military and government installations use portions of the 5 GHz space for ground tracking stations and satellite communications. To ensure that unlicensed applications do not interfere with existing 5 GHz applications, the ETSI has specified that two additional protocols must be implemented before distribution is granted in Europe. These protocols, DFS (Dynamic Frequency Selection) and TPC (Transmit Power Control), allow the wireless client/application to dynamically respond to radio interference by changing channels, using lower power modulation or both and have been implemented in HiperLAN2. This ensures that the “incumbent” signal gets first priority when a new signal is introduced in a given area. DFS and TPC

implementations for 802.11a are being discussed, and we expect an addendum to the 802.11a standard to allow these features as options.

## Unifying the Standards — United We Stand Divided We Fall

Manufacturers are concerned over the divergence of 802.11a and HiperLAN2 standards: Having to build and support two separate products is a significant burden in terms of both development and marketing, and the increased development costs will be handed down to the end user. Several companies such as Atheros Communications have proposed a standard, called 5-UP (Unified Protocol), that would provide extensions to 802.11a and HiperLAN2, letting both technologies interoperate at low, medium, and high speeds. The 5-UP standard also specifies a method for selecting subchannels for transmission within a carrier. If this portion of 5-UP were adopted, it could allow devices such as wireless phones, Bluetooth products and other narrow-bandwidth applications to use a part of the 5 GHz spectrum without having a significant impact on network performance. This would help prevent the saturation and congestion problems that have arisen in the 2.4 GHz space. Atheros has submitted the 5-UP standard to the IEEE for consideration, but no decision has been made as to whether anyone other than Atheros will support it.

For implementers, 802.11a's use of the same MAC as 802.11b means one less component to design. For adopters, this means that upgrading from 802.11b to 802.11a technology will not have significant impact on network operations. 802.11b's MAC uses CSMA/CA technology and implements a number of options to improve throughput, especially in congested areas.

The only drawback to using the 802.11b MAC is that 802.11a inherits the same inefficiencies hampering 802.11b wireless solutions. The 802.11b MAC is only about 70 percent efficient, so even at 54 Mbps, maximum throughput is closer to 38 Mbps. Factor in driver inefficiencies and some additional overhead at the physical layer, and you can expect actual throughput to be about 30 Mbps. We estimate this throughput based on the average throughput of 802.11b networks, which is now about 6 Mbps of a possible 11 Mbps for optimal implementations. Unlike 802.11b, 802.11a does not have to transmit its headers at 1Mbps, so 802.11a will gain some theoretical efficiency over 802.11b; still, it is safe to speculate that throughput won't exceed 35 Mbps.

IEEE 802.11a provides fast data access and has been fairly quiet about voice and video support, much like Fast Ethernet. However, HiperLAN2 boasts an ATM like qualities of multimedia support, is a technology that does not seem to be gaining market momentum in the United States and Asia. We all know the fate of ATM in wake of Ethernet technology, and this is surely a fate HiperLAN2 does not want to see happen to itself.

---

## Chaos

There is clearly chaos in the WLAN market place. There are several wireless technologies and standards trying to address the same problems. Each standard has its pros and cons and quite a few of them are in conflict with complementary technologies. Each technology has different specification versions and standards, and these keep changing from time to time for adding more functionality, bug fixing, and adaptation of new standards. The public areas, the home, SOHOs and enterprise all support varying technologies.

While the 2.4 GHz has only one WLAN technology, it is infested with other technologies such as Bluetooth and HomeRF, not to mention microwave ovens, baby monitors and cordless phones. The 5 GHz spectrum has only two technologies, but these are very disparate in nature. Having two technologies sharing the PHY layer,

going after the same market and applications, does nothing more than create chaos for the product manufacturer, implementers and most of all the consumer. Adding to the chaos is the inability of all these products to work together. The challenge for product manufacturers is to interoperate with these technologies, bridge to the different system interface and have to ability to migrate to the latest in evolving specifications.

---

## **Programmable Logic Solutions Enable WLAN Products**

WLAN products include network interface cards (or NICs/PC adapters), APs (end-user-to-LAN and LAN-to-LAN) and technology bridges for communications. NICs provide an interface between the end-user device (desktop PC, portable PC, or handheld computing device) and the airwaves via an antenna on the APs. APs act as transmitters/receivers between wired and wireless networks. They connect to the wired network via standard Ethernet cable (token ring is available, but less common) and use airwaves to transmit information to and from “connected” wireless end users. Technology bridges exist at the periphery of each product and are the most susceptible to constant change and evolution. These products need a flexible, reprogrammable and low-cost platform to accommodate for time-to-market pressures, specification changes, lack of clear direction, and short product lifecycles.

PLDs have always provided time-to-market advantage over ASICs and ASSPs. In this cost sensitive and quickly developing market, there is a need to develop products fast at low costs. Aggressive process technology adoption has allowed FPGAs to obtain more die per wafer, provide more logic, offer increased performance, and accommodate various ASIC-like features required to allow system integration. This has been fundamentally instrumental in narrowing the wide gap between FPGAs and ASSPs. FPGA vendors, by virtue of the benefits reaped through process technology now have the capability to bring traditional FPGA benefits to the cost-sensitive home networking and WLAN markets. Xilinx FPGAs are based on SRAM technology and can be re-programmed an unlimited number of times. Field upgradability provides the ability to update functionality of the FPGA requiring a simple update to the FPGA configuration bit-stream. FPGAs allow designers to gain market share by bringing them to market sooner than a stand-alone ASSP. Designers can also take advantage of the fact that the solution now allows them to upgrade their hardware and stay in the market-place longer, adapt to specification changes and thus maximize profitability.

With the introduction of Spartan-II FPGAs, in January 2000, Xilinx extended its playing field into the low cost market. The Spartan-II family provides increased densities (up to 200,000 system gates) and system-level features (such as DLLs, BlockRAM and SelectIO) at a much lower cost. FPGA gates left over from programming the MAC may be used to customize the end products, and be used for additional functionality such as memory (SRAM, DRAM and flash) controllers, PCI controller, UARTs, and forward error correction (FEC). While FPGAs help eliminate bugs and incompatibilities, Spartan-II FPGAs and Xilinx IRL (Internet Reconfigurable Logic) program allow remote specification updates

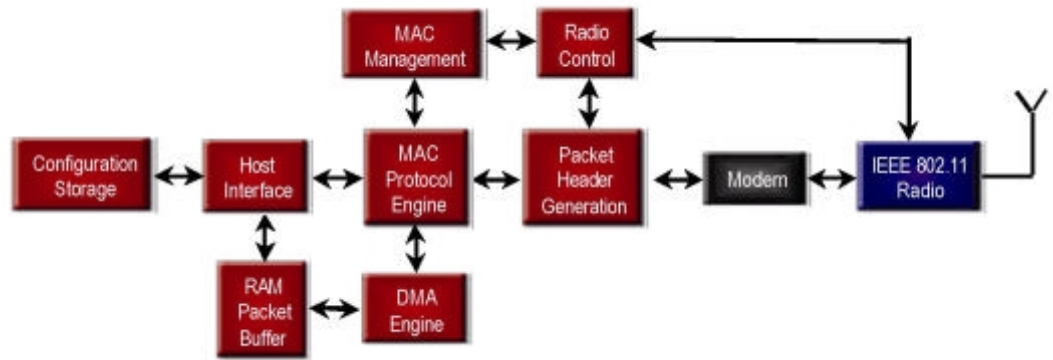


Figure 12: Spartan-II FPGAs in NIC/PC Cards

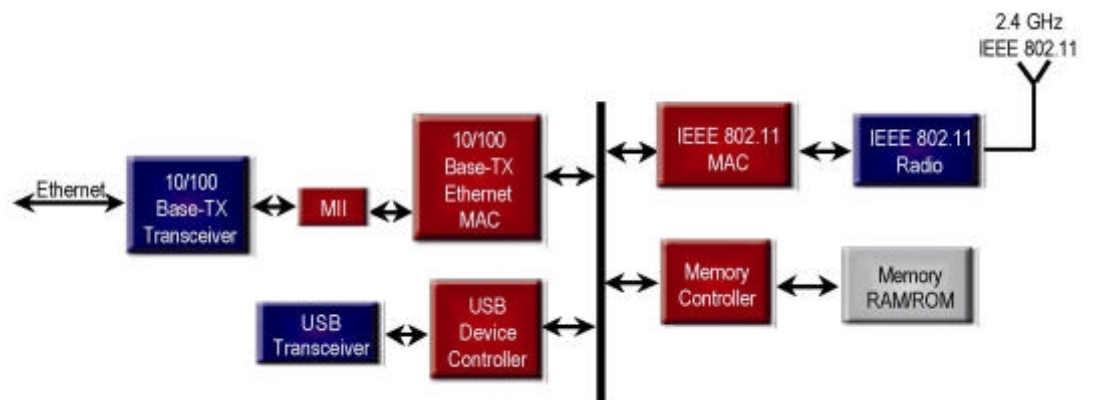


Figure 13: Spartan-II FPGAs in WLAN APs

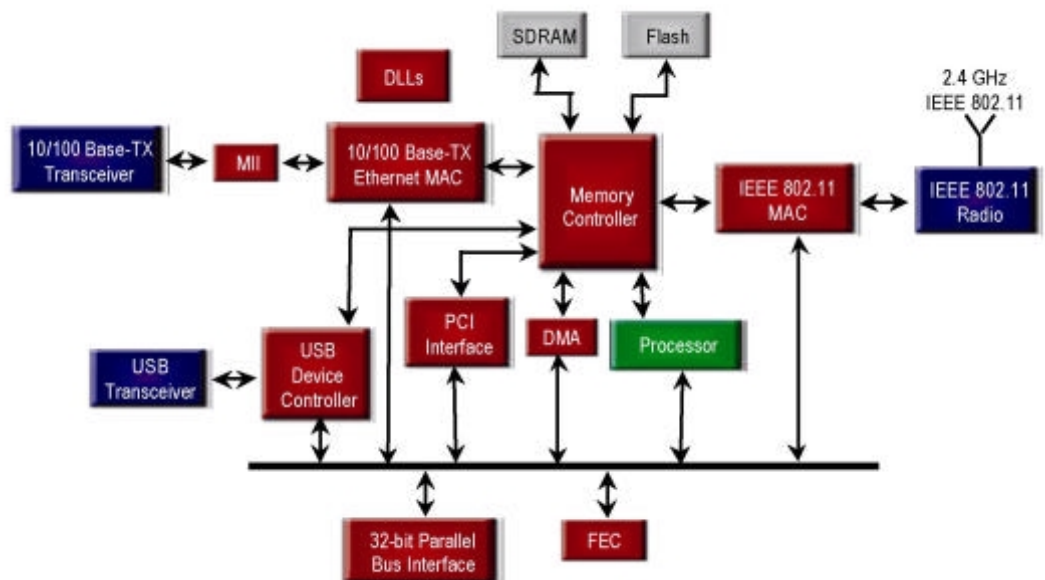


Figure 14: Spartan-II FPGAs in (WLAN to Ethernet) Technology Bridges



## NIC/PC Cards

**Figure 12** shows the WLAN card, which consists of the antenna, radio/PHY, baseband controller and the MAC. The role of FPGAs is highlighted in Maroon. The block diagram of the PC Card shows that the Spartan-II FPGA provides functionality of a WLAN MAC (radio control, packet header generator, MAC protocol engine, DMA engine, RAM packet buffer, host interface, configuration storage and MAC management), memory controller and as an interface to the PC.

## Access Points

The APs are devices that provide a wireless hub or a gateway for non-wireless networks to wireless networks. They also act as the network police and perform network management. They receive, buffer and transmit data between WLAN and the wired network infrastructure. APs function within a range of 100 to several hundred feet. They also connect WLANs to other technologies such as USB and Ethernet. In **Figure 13**, Spartan-II FPGAs provide solutions in APs such as memory controller, Ethernet MAC, USB device controller and IEEE 802.11 MAC.

## Technology Bridges

Conflicting specifications and lack of a clear direction create the need for FPGA-based technology bridges. It is also quite likely that some of these conflicts may never get resolved. It would be nearly impossible and cost-prohibitive for a supplier of home networking and WLAN products to cater to all the various specifications and changing needs. At the same time betting on the success of one single product may preclude them from being successful in the marketplace. **Figure 14** shows an example of a WLAN to Ethernet technology bridge.

In the technology bridge example, Xilinx Spartan-II FPGAs are at the heart of the technology bridges, which usually connect unlike technologies — such as WLANs to Ethernet. While the Ethernet MAC has been around for a long time, the IEEE 802.11 specification that defines the MAC and PHY layers continue to evolve. With IEEE 802.11a and HiperLAN2 specifications still not defined, it seems ideal for the MAC and MII (media independent interface) to be programmed in an FPGA. Similarly, the HomePNA, HomeRF, FireWire, USB, HiperLAN2, Bluetooth are all technologies with evolving specifications.

WLAN products will extend beyond NICs, APs, and technology bridges, and will enable every device in the home, SOHO, and enterprise with WLAN capabilities. For example, devices such as digital TV, residential gateways, set-top boxes, digital modems, PC peripherals, gaming consoles, and other appliances. Spartan-II devices are used for:

- I/O Control: Multiple front-end interfaces (DSL, cable, satellite, powerline, wireless, analog) and multiple back end interfaces (USB/USB 2.0, HomePNA, HomeRF, FireWire, Bluetooth, and Ethernet)
- Hard disk drive interface
- Clock distribution using on-chip DLL circuits
- MPEG decoder
- MAC (Fast Ethernet)
- Forward error correction (FEC) algorithms: Reed-Solomon, Viterbi
- Memory solutions: On-chip memory (Distributed memory, BlockRAM) and Memory controllers (Flash controller, SRAM controllers, DRAM controllers)



- CPU (microprocessor and microcontrollers)
  - HDLC controller, ADPCM
  - PCI and interface to other system interconnectivity technologies
  - Glue Logic (LCD controllers, UARTs, DMA controllers)
- 

## Summary

The WLAN market is growing fast with a promise to penetrate public areas, homes, SOHOs and enterprises in large volumes. IEEE 802.11b, IEEE 802.11a and HiperLAN2 are the main technologies in the WLAN market. While 802.11b products have been very successful in the market, migration to the 5 GHz spectrum is essential for achieving the higher data rates necessary. IEEE 802.11a and HiperLAN2 are very similar in the PHY layer both technologies use; however, the MAC layer is entirely different. The PHY layer for 802.11b is based on DSSS, while 802.11a and HiperLAN2 use OFDM. 802.11b and 802.11a uses the CSMA/CA algorithm in the MAC layer, which is ideal for data communications but is not ideal for voice. HiperLAN2 adopts an entirely new MAC layer that is based on TDMA and TDD, which is ideal not only for data but also voice, video and other real-time applications. Current 802.11b products provide 11 Mbps data rates, and both 802.11a and HiperLAN2 promise a much faster 54 Mbps.

However, the duel between the two technologies is just getting started. The uphill battle for product manufacturers, implementers and consumers begs the question that why do we have two technologies, with the same PHY layers, same data rates, targeting the same markets, but still disparate in the protocol translation. The next few years will see either the unification of the two technologies or one out market the other, similar to what Ethernet technology has done to ATM. Price and marketing will be a key factor in influencing which technology eventually succeeds.

Being a cost sensitive and evolving market with multiple technologies vying for market share, WLAN products require low-cost programmable logic solutions. Programmable logic solutions allow customers to realize time-to-market and time-in-market advantages. Spartan-II FPGAs with increased densities, system-level features, an extensive IP portfolio and low costs, provide an ideal solution for WLAN products such as NIC cards, APs, technology bridges, and other products. Xilinx Spartan-II FPGAs provide the flexibility needed in the wireless LAN market and products to update specifications and standards, and to interface with other technologies. They provide interoperability between different technologies, which is essential for the success of this market.

---

## Acronyms and Glossary

**AP** – Access Point

**ARQ** – Automatic Repeat reQuest

**CSMA** – Carrier Sense Multiple Access

**CSMA/CA** – Carrier Sense Multiple Access with Collision Avoidance

**CSMA/CD** – Carrier Sense Multiple Access with Collision Detect

**ETSI** – European Telecommunication Standards Institute

**FPGA** – Field Programmable Gate Array

**GHz** – Giga Hertz (billion cycles per second)

**HiperLAN2** – High Performance Radio LAN

**IEEE** – Institute of Electrical and Electronics Engineers

**ISM** – Industrial, Scientific and Medical

- MAC** – Medium (Media) Access Control
- MAN** – Metropolitan Area Networks
- Mbps** – Mega Bits per second
- OFDM** – Orthogonal Frequency Division Multiplexing
- PHY** – PHYSical layer
- SOHO** – Small Office Home Office
- TDD** – Time Division Duplexing
- TDMA** – Time Division Multiple Access
- UNI** – Unlicensed National Information Infrastructure
- WECA** – Wireless Ethernet Compatibility Alliance
- WLANs** – Wireless Local Area Networks

## References

1. HiperLAN2 Global Forum
2. Enabling Fast Wireless Networks with OFDM, Jim Geier, CSDesign, February 2001

## About the Author

Amit Dhir is a system architect in the strategic marketing group at Xilinx, primarily responsible for evangelizing new and emerging vertical markets such as Networking, Optical, Wireless, Embedded, Telecom, and Consumer. Amit can be reached at [amit.dhir@xilinx.com](mailto:amit.dhir@xilinx.com).

## Revision History

The following table shows the revision history for this document.

Date	Version	Revision
08/01/01	1.0	Initial Xilinx release.