

Wireless Local Area Networks: Issues in Technology and Standards

Executive Summary

The past decade has seen the emergence of wireless local area networks as a valuable adjunct to the wired LAN. Wireless LAN technology has evolved from low data rate, interference-prone products at 900 MHz and 2.4 GHz to RadioLAN's fourth generation 5 GHz systems giving wired network data rates. In enterprises with a large installed wired network infrastructure, a wireless LAN overlay can heighten the value of the network to mobile, laptop PC equipped users. In a small business that is faced with frequent modifications to its LAN infrastructure, a wireless LAN offers a lower total cost of ownership through easy reconfigurability.

The technology for implementation of wireless LAN has evolved over the past decade driven by continued gains in semiconductor performance. The need to simplify installation has led to operation in the unlicensed Industrial-Scientific-Medical bands. Both the 900 MHz and 2.4 GHz bands have been utilized for wireless LAN applications. The requirement of operating in competition with a number of interfering users like microwave ovens and other high power industrial applications has forced the adoption of spread spectrum technology. Unfortunately, even the most complex spread spectrum modulation schemes can not prevent performance degradation in the face of the increasing number of users at 2.4 GHz. The solution to this problem, which will eventually be adopted by other WLAN vendors, is to operate in the 5 GHz bands. A 5 GHz solution offers greater available bandwidth and freedom from much of the interference that exists in the lower bands. The newly allocated Unlicensed-National Information Infrastructure bands around 5.2, 5.3 and 5.775 GHz are dedicated solely to high data rate communication systems—RadioLAN offers the only products approved for use by the US Federal Communications Commission in the U-NII bands.

A number of standards have evolved and are continuing to evolve in an attempt to provide interoperability among various equipment vendors. The extreme range of user requirements coupled with the entrenched interests of existing suppliers has made the standards setting process slow and compromise-ridden. Consequently, not only do the existing standards lag technology innovation by years, but the compromises built into the standards prevent the broad interoperability hoped for by both users and standards organizations. The recently adopted IEEE 802.11 standard is an example of the results of this process. To make matters even worse, the wide range of user needs have led to competing standards such that systems cannot even coexist in the same frequency bands without interference. The result is that the inability of standards to keep pace with innovation has led to a set of WLAN standards that offer no value to the user.

RadioLAN has chosen instead to adhere to the mature network standards like Ethernet (802.3), which guarantees that the users investment in networked applications is protected and enhanced by the value of wireless connectivity.

Since the RadioLAN MAC protocol is based upon a wireless implementation of 802.3, long-term protection of a large investment in existing network software and the applications that run on the network is assured. To guarantee that network performance will not degrade over time, the best option is to choose a network solution that does not operate in a band shared with potential interferors like microwave ovens and cordless telephones. The selection of a 5 GHz WLAN offers the best alternative to the increasingly crowded 2.4 GHz band. RadioLAN offers the only 5 GHz solution available today.

Introduction and Background

Local Area Networks have evolved over the past 20 or so years to become a crucial ingredient in the success of businesses, large and small. From the smallest office to the largest multinational corporation shared access to information resources is an indispensable part of modern business processes. Local Area Networks (LAN) have been traditionally connected with wired infrastructure and a multi-billion dollar industry has grown up to supply customer's needs for wired networking products. Companies like Cisco, 3Com, Bay Networks and Cabletron have developed a vast range of products to implement and manage Local Area Networks of all sizes and to interconnect them throughout the enterprise.

Over the past ten or so years an alternative to wired LAN structures has evolved in the form of the Wireless LAN (WLAN). In a manner analogous to the growth of the wired LAN, initial application and market success of the WLAN was in specialized, vertical markets. Thus applications that highly valued the mobile, untethered connectivity were the early targets of the WLAN industry. These first generation products, which operated in the unlicensed 902-928 MHz ISM (Industrial Scientific and Medical) band had limited range and throughput, but proved useful in many factory floor and warehouse applications. These systems took advantage of emerging semiconductor processes developed for cellular telephone applications to enable inexpensive WLAN products. Unfortunately these same inexpensive components also enabled a wide variety of other 900 MHz products like cordless telephones. Consequently, the band quickly became crowded with a variety of unlicensed products. Building upon technology originally developed for military applications, spread spectrum techniques were employed to minimize sensitivity to interference. This approach allowed the design and manufacture of 900 MHz WLAN products having nominal data rates of 500 kilobits per second. Ultimately, the growing popularity of the band for a large range of unlicensed products, aggravated by the limited bandwidth caused users of WLAN to look to a different frequency band for growth in performance.

The second generation of WLAN products evolved in the 2.40-2.483 GHz ISM band. Again enabled by semiconductor advances, this time from the PCS market, products were developed by a number of manufacturers for this band, again generally for specialized vertical markets. Because a major user of the 2.4 GHz ISM band is microwave ovens, a transmission scheme less sensitive to this type of noise source needs to be used. Extending the experience from the crowded 900 MHz band, spread spectrum techniques combined with more available bandwidth and more complex modulation schemes allowed second generation 2.4 GHz band products to operate at data rates of up to 2.0 megabits per second. Third generation WLAN products are evolving to more complex modulation formats in the 2.4 GHz band to allow nominal 11 megabit per second raw data rate and about 7 megabit per second throughput even as the decreasing cost of 2.4 GHz semiconductor technology allows for ever more use of this band. In the third and fourth quarters of 1998, the first 2.4 GHz cordless telephones became available as did several new consumer electronic PC interconnection products. The history of the 900 MHz

band WLAN seems poised to repeat itself as the 2.4 GHz band becomes a victim of its own success.

The fourth generation of WLAN technology, offering users data rates of 10 megabits per second and up, is beginning. Again evolving from advances in semiconductor technology, fourth generation devices are operating at a new, higher frequency—the 5 GHz band. The first of these fourth generation products has been available from RadioLAN Inc since late 1996. The initial products operate in the 5.775-5.850 GHz ISM band, and additional bandwidth around 5.2 GHz has also been made available. Unlike the lower frequency bands used in prior generations of WLAN products, the 5 GHz bands do not have a large “indigenous population” of potential interferors like microwave ovens or industrial heating systems as was true at 900 Mhz and 2.4 GHz. In addition there is a much more bandwidth available at 5 GHz—350 Mhz compared with 83 Mhz at 2.4 GHz and 26 Mhz at 900 MHz. This combination of greater available bandwidth and reduced sources of interference make the 5 GHz bands an ideal region in which WLAN products having performance comparable to that achieved by wired networks are being created.

A Wireless LAN can enhance the value of installed wired networks in large corporations by offering untethered mobility and reduce the total costs of network ownership in small companies by easy reconfiguration with growth and change. In the sections below, a brief review of data networks will be presented. This will be followed by a section on the various technology issues surrounding WLAN and finally by a discussion of the different standards relating to WLAN.

Network Structures

To provide a basis for the further discussions of the technology and standards issues related to WLAN, a brief review of network structures is in order. The first concept to keep in mind is that networks represent an interactive collection of often powerful computers. The complexities of the interactions among these members of the network are many. To provide a common framework for describing and understanding, the International Standards Organization approved a standard called ISO-7498 that defines a seven-layered model to describe the interconnection processes between various members of a network. This model, which is officially known as the Open System Interconnect model, is the basis for most discussions of network function. The seven layers are shown in Figure 1. WLAN products, in common with other networking products, typically work at the two bottom most layers of the 7-layered model. The Physical Layer (usually referred to as simply PHY) is the actual physical method by which data is passed from one member of the network to another. For a WLAN its description includes such things as frequency of operation, data rate, modulation method, etc. In addition to the PHY, the lower half of the Data Link layer, usually known as the Media Access Control (or MAC) layer is defined by the WLAN product. The MAC layer is conventionally defined as the protocol by which data is transferred between network members. In Figure 1, the shaded areas represent the PHY

and MAC layers. These layers and their important features will be discussed in the Technology section that follows.

Wireless networks are implemented with two basic types of components: a Network Adapter which is the electronic interface between the client

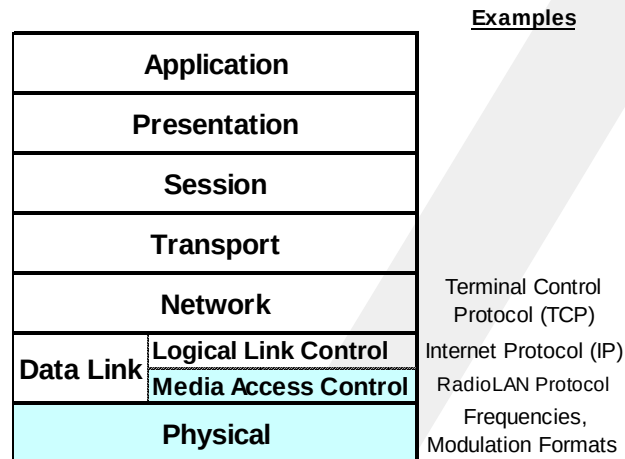


Figure 1: Open System Interconnect Model

computer (these days often a notebook PC) and the wireless network and an Access Point which provides the bridge between the wireless network and a wired network. A wireless network can consist solely of Network Adapters connecting members of a completely wireless network, or a combined network in which wired and wireless connectivity is employed. Because a client, wireless-networked computer could appear as a member of any number of potential networks due only to the client's own mobility, the topology of the network in which the new client appeared is altered by the additional member as is the network geometry.

Although there are two basic types of wireless network components, the wide variety of possible client computer platforms require many variations. Within the IBM-PC compatible environment, the network adapter could be required to work with the ISA or PCI bus structures as well as the PCMCIA interface. Extending beyond the IBM-PC are other personal computers like the Apple Macintosh family, the evolving set of handheld or smaller format machines running the Windows CE operating system, and a wide range of workstation class machines. Each of these families of platform requires not only possibly unique hardware interfaces, but also unique driver software which works at the Transport layer in the OSI model. For Access Point products there is the requirement to interface with any of several possible wired LAN types and also be transparent to whatever higher layer software is in use elsewhere in the network.

Wireless LAN Technology

Wireless LAN PHY Implementations

The most important requirement for any network structure is to provide adequate levels of service to each member of the network. This service requirement has dimensions of both access to the network and bandwidth on the network. As new users are added to the network, additional network capacity must be added to provide both convenient network access and the desired bandwidth. The methods of adding capacity are well known, and have been long employed by network managers. In a wireless network, additional capacity can be provided by a number of methods depending upon the WLAN technology employed. The options available for increasing capacity are functions of fundamental considerations made in the design of the MAC and PHY layers of the particular wireless network.

Historically WLAN PHY layers have been designed around a combination of low cost semiconductor technology and available spectrum. To simplify the use of WLAN, frequencies have been conventionally chosen from the unlicensed ISM bands. Although the general rules for these bands are that everyone is free to use them and must accept the interference from other users, national regulatory bodies, like the Federal Communication Commission in the US, have set general standards governing types of modulation and maximum permissible power levels. Similarly in Europe the European Telecommunication Standards Institute has set guidelines for member of the European Union. Elsewhere, other governments have adopted the FCC or ETSI regulations to meet their local needs. In general, the 900 MHz band does not have sufficient bandwidth to allow usefully large networks with sufficient data rates to support most current networking requirements. At 2.4 GHz the FCC has allocated 83.5 MHz of bandwidth to WLAN applications. To operate successfully in competition with other interfering users in this band, WLAN are implemented using spread spectrum technology. Spread spectrum systems utilize two different techniques to spread the required bandwidth over a larger range of frequencies than would be necessary to simply transmit the data.

In a Frequency Hopping Spread Spectrum (FHSS) system, the data is modulated on to the carrier in a manner identical to that employed for standard narrow band communications. Most frequency hopping systems employ Gaussian Frequency Shift Keyed modulation, either two or four level. The carrier frequency is then changed (“hopped”) to a new frequency in accordance with a pre-determined hopping sequence. If the receiver frequency is then hopped in synchronism with the transmitter, data is transferred in the same manner as if the transmitter and receiver were each tuned to a single fixed frequency. If different transmitter-receiver pairs hop throughout the same band of frequencies, but using different hopping sequences, then multiple users can share the same frequency band on a non-interfering basis. The operation of a pair of frequency hopping transmitter-receiver pairs is shown schematically in Figure 2. The obvious question arises: why not just assign a fixed frequency to each user and share the bandwidth in that manner? The answer

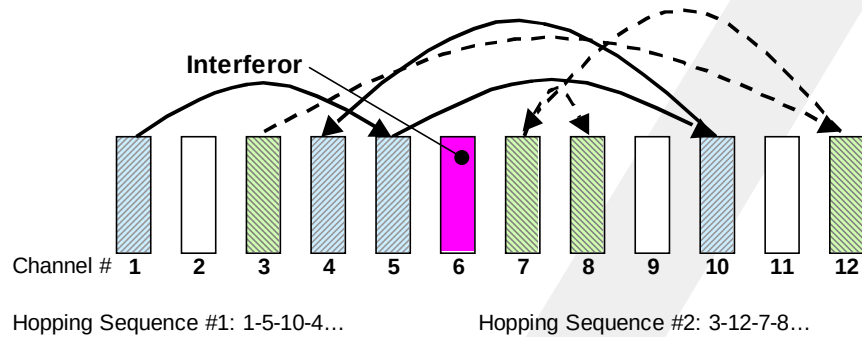


Figure 2: Frequency Hopping Spread Spectrum

lies in how a FHSS responds to interferors. If a particular hop channel is noisy due to a fixed frequency source (e.g. a microwave oven), then information transferred in that particular channel can be lost. The system then hops to the next frequency, which is hopefully not occupied by an interferor, and information transfer continues. As will be discussed below, the communication protocol employed in the design of the system can offer means of further reducing the impact of a noisy channel. In the 2.4 GHz band, there are 79 1.0 MHz wide channels assigned, and a total of 78 different hopping sequences. In theory, all 78 hop sequences could be shared on a non-interfering basis, but statistically only about 15-20 (depending on individual user data traffic patterns) can be used. Thus a network manager could assign 15 different hopping sequences in the same physical area with minimal interference. This has the effect of multiplying the total available bandwidth by 15 times although each individual user would only experience a 2 Megabit per second maximum data rate.

The second type of spread spectrum is known as Direct Sequence Spread Spectrum (DSSS). In this system, the data stream is multiplied by a pseudo-random spreading code to artificially increase the bandwidth over which the data is transmitted. This is shown in Figure 3. The resulting data stream is then modulated onto the carrier using either Differential Binary Phase Shift Keying or Differential Quadrature Phase Shift Keying. By spreading the data bandwidth over a much wider frequency band, the power spectral density of the signal is reduced by the ratio of the data bandwidth to the total spread bandwidth. In a DSSS receiver the incoming spread spectrum data is fed to a correlator where it is correlated with a copy of the pseudo-random spreading code used at the transmitter. Since noise and interference are by definition de-correlated from the desired signal, the desired signal is then extracted from a noisy channel. While the block diagram of a DSSS WLAN product is somewhat simpler than a FHSS product, there are some very subtle difficulties that come into play in the presence of strong interfering signals. The basis of the noise immunity of a DSSS system is the fact that the

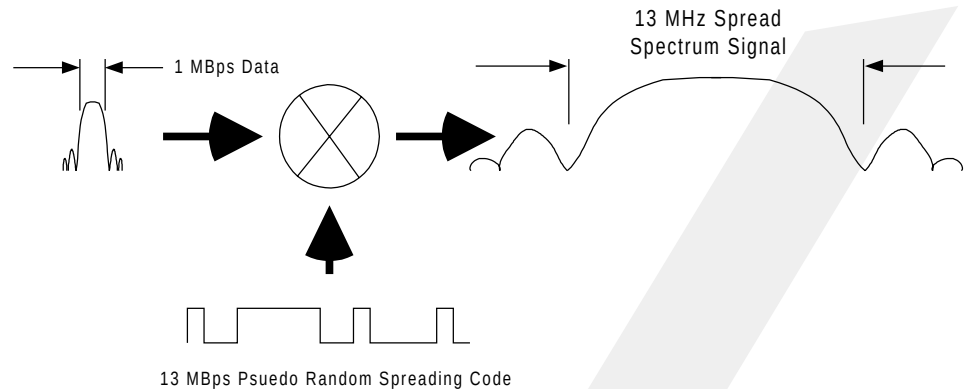


Figure 3: Direct Sequence Spread Spectrum

desired signal and interference or noise is uncorrelated. In complex interference environments which are becoming more common as usage increases, particularly ones in which very strong signals maybe present, non-linearities in the receiver generate intermodulation distortion products between the desired signal and the interfering signals. These IM products are now correlated with the desired signal thus reducing the resulting signal to noise ratio when processed in the receiver. The usual implementation of DSSS in the 2.4 GHz band employs a 13 MHz wide channel to carry a 1 MHz signal. Channels are centered at 5 MHz spacing, giving significant overlap. Within the designated 2,400 to 2,483 GHz band there are eleven available channels for users in the US. In a practical network, there are typically three non-overlapping channels that can be utilized in deploying a network. In an analogous manner to that described for FHSS, the total bandwidth in a physical region could effectively be multiplied by a factor of three for DSSS networks, although each user would again only experience 2 Megabit per second throughput.

In the 5 GHZ bands the PHY related issues become much simpler: there are fewer interferors and more bandwidth is available. Consequently, WLAN system designers have more options available to provide higher performance, lower cost networks. At present, there is only one 5 GHz WLAN manufacturer, RadioLAN Inc., but over the next one to two years, the ten or so manufacturers of lower frequency WLAN products may also announce 5 GHz products. Because of the advantages afforded by operation at 5 GHz, the RadioLAN product is able to offer 10 megabit per second performance at a price less than two megabit, 2.4 GHz products. This is accomplished by means of a Differential Pulse Position Modulation waveform that is elegant in its simplicity. This modulation format offers a number of advantages to WLAN system designers that translate into performance superior to systems operating at 2.4 GHz. An important advantage to the 5 GHz band compared to the lower frequency bands is the creation of bandwidth at 5.2 and 5.3 GHz dedicated exclusively to data transmission in addition to the ISM

Wireless LAN MAC Implementations

band at 5.8 GHz. These three segments have been designated by the FCC as Unlicensed-National Information Infrastructure (U-NII) bands exclusively for high speed data transmission. As such the problems associated with either microwave ovens or high power industrial microwave power sources that exist at the lower bands have no relevance at 5 GHz. Further, the lack of interference in the 5 GHz bands frees WLAN designers to optimize system design in terms of data rate, energy efficiency, cost and other parameters of greater value to the WLAN user, rather than focusing design efforts on coexisting with high power interferers.

WLAN MAC implementations try to follow the general intent of the Ethernet standard in terms of channel sharing. Ethernet uses a Carrier Sense Multiple Access/Collision Detection protocol to arbitrate attempted simultaneous channel usage. Thus if multiple users try to communicate at the same time, a “collision” is detected causing each user to wait a randomly chosen interval and then attempt transmission again. In wireless environments it is not feasible to detect collisions, so a “Collision Avoidance” protocol is employed. In this protocol, a “listen before send” procedure is established—each user listens to determine if the channel is in use before attempting to transmit data. If the channel is already in use by another network member, the user attempting to send data stops and, as in Ethernet, waits a randomly chosen time and then attempts the transmission again. This protocol fairly assigns channel capacity among all users and also affords a measure of interference protection. In the circuit implementation of the Collision Avoidance protocol, the receiver simply listens for the presence of a signal level, rather than actually trying to process the signal to determine its possible data content. Thus any signal level, above some preset threshold causes the user to stop and wait before transmission. The impact of this protocol on channel throughput is well behaved with performance degrading in a graceful fashion with traffic density. In the case of interference from some signal not obeying the Collision Avoidance protocol, the impact can be quite severe. Of particular importance at 2.4 GHz is the potential interference from microwave ovens. This type of interference has the potential of effectively reducing network capacity for DSSS systems by 50%. Harris Semiconductor, a major supplier of DSSS components puts the following warning in their Application Note:

“Additionally, the microwave oven has been identified as an interference source of concern within the 2.4GHz ISM band. The oven is a pulsed source with about a 50% duty cycle. The gaps allow messages of about 1000 bytes through at the 1 MBPS rate.”[1]

Although most, if not all, WLAN MAC protocols start from the general precepts of the Ethernet, there are special implications in WLAN structures (like the Collision Avoidance vs Collision Detection concept discussed above) that require some variations from the usual Ethernet features. For instance, in a wired network, there is no need for a roaming function, typical of laptop users, in which a user can move in and out of contact with other

members of the network. In a wired network a user is either connected to the network at a particular location or not; it is not possible that the user might be able to move from one portion of the network to another. Several different MAC protocols have been developed by different WLAN manufacturers, and while all are generally similar there is an important distinction in the extent to which they replicate the Ethernet functions. Since the overwhelming majority of corporate networks are built around Ethernet connectivity, it is highly important that any wireless overlay to the network support all the Ethernet functions expected by the network operating system. This is even more important with high data rate networks since they offer the possibility of operating small to mid-sized networks in a totally wireless fashion. Several of the more widely used 2 megabit data rate WLAN MAC require the presence of an Access Point to perform the bridging function between the wireless protocol and the Ethernet. Thus, if a network is set up having only wireless members (the so called *ad hoc* mode) and no Access Point, there may not be support for all the Ethernet functions required by application software. This possibility does not exist in products like the RadioLAN WLAN product family that have been designed for total Ethernet compatibility.

Wireless LAN Standards

The topic of standards and their relevance to WLAN products is the subject of near endless discussion among the proponents of the many products and standards in the WLAN market. In the material that follows an attempt will be made to put in perspective the issue of standards, their function, the mechanism by which they are created and their importance to users of WLAN.

Why are Standards Needed?

What we know today as standards first evolved late in the Industrial Revolution. To enable suppliers to provide components for much of the new industrial machinery being developed, interchangeability of items like fasteners was required. Industry leaders agreed among themselves on a set of relevant specifications for items like nuts and bolts and suppliers then produced to them to those specifications. Thus suppliers are guaranteed multiple markets for the same product and customers are given the option of procuring interchangeable products from multiple sources. Ideally, a standard should allow interoperability among products from different manufacturers, or if that is impossible at least allow non-interfering coexistence among equipment from a mix of suppliers. If either of these two criteria is satisfied, then the customer's investment is protected because it would be possible to purchase products from multiple vendors offering the same or similar performance.

The heart of the standard setting process is the assumption of stability over time of the specifications that the standard is trying to control. In a technology as rapidly evolving as WLAN, standards are made obsolete soon

Who Sets Standards and How?

after they are approved. In response, those setting standards often attempt to lead the technology or devise standards that have room for growth. This process often leaves the user faced with the uncomfortable option of adopting a new technology solution for which a standard does not yet exist in order to gain the advantage offered by the new technology. If a sufficient number of users adopt the newer technology then a *de facto* standard can be created. The *de facto* standard can then often be adopted by standards setting bodies. Examples of this are many in the quickly changing data communication world—one of the better known examples is the adoption of the 10Base-T Ethernet standard.

Standards for data communication networks are set by three different classes of organizations: government regulatory bodies who are given statutory authority to manage the aspects of communications impacting the general public; national or international standards organizations who maintain the large body of standards covering many other topics besides simply data communication; and voluntary groups of industry members who agree on a standard among themselves.

In the WLAN industry the governmental agency that has oversight of issues such as frequency allocation, output power levels, etc. is the Federal Communications Commission in the US and its counterparts in other countries. The US, in common with most other nations, is a member of the International Telecommunications Union that attempts to harmonize issues like frequency allocations among its members. This allows some degree of commonality of frequency usage in different countries. The regulatory trend in the US, as well as in other ITU member states, has been to open new frequency bands to facilitate new wireless communication services. For example, the US in 1997 statutorily mandated creation of new frequency bands in the 5 GHz region for the Unlicensed-National Information Infrastructure (U-NII). Other countries are currently studying the feasibility of allocating similar frequencies. In addition to the governmental standards allocating frequency bands and usage, governmental regulations also cover the unintended emissions from electronic equipment. These regulations ensure that out-of-band emissions do not interfere with other equipment.

The primary standards body creating and maintaining standards for the data networking industry is the Institute of Electrical and Electronic Engineers. Within the IEEE standards structure, data networking standards fall under the general category 802. Thus, all IEEE data networking standards have a general category of 802, followed by another designator signifying the specific topic. In this context, 802.1 covers certain aspects of network organization, 802.3 is the IEEE standard for the Ethernet, 802.11 covers WLAN and there are many others. In addition to the IEEE there are other organizations setting standards relating to WLAN. The European Telecommunications Standards Institute (ETSI) is engaged in creating standards to cover a high speed WLAN service called Hiperlan. Within other nations, the national telecommunications authority has taken some level

of control over WLAN standards. For instance, in Japan local regulations require the periodic transmission of the individual WLAN transmitter's call sign, thus requiring changes in both the MAC and PHY layers of the WLAN products for the Japanese market.

A third category of standard setting organization is the industry consortium. In this structure a group of industry members agree among themselves on a set of common specifications for their products. These specifications are then published by the consortium as a standard for use by anyone wishing to make products in that category. There are several examples of this structure, one of the better known ones is Personal Computer Memory Card Interface Association or PCMCIA. Originally set up to coordinate standards for laptop computer plug-in memory cards, the PCMCIA standard now defines the interface specification for a wide range of portable computer accessories. In the WLAN area there are two significant consortia defining standards for next generation WLAN. The first group is the HomeRF Working Group. The HomeRF Working Group was created in late 1997 to provide a set of standards for wireless consumer electronics products. The Bluetooth Special Interest Group was created by the major cellular telephone companies to provide a replacement for the cable connection between mobile PC platforms and cellular telephones. These two groups are similar in that they have goals of creating standards for very specific set of applications, not the more general specifications envisioned by the IEEE standards.

In addition to understanding the various organizations that create standards, it is also important to understand how the standards are created. Standards set by governmental organizations generally follow the process used by the FCC. The legislative branch grants statutory authority in the form of general guidelines. The FCC then formulates proposed regulations and public comments are solicited. Following the period of public comments, the FCC formally issues the new regulations often reflecting the input from the public comments. In the case of the IEEE standards, a committee is formed from industry and academic interests and the specifications for the standard are drafted. Because of the breadth of the standards addressed by organization like the IEEE, the deliberations are often lengthy—the 2 megabit 802.11 deliberations took seven years. The final decision on the standard is reached by vote of the committee members. The voting rules within the IEEE committees vary somewhat, within the 802.11 committee voting membership is granted to anyone attending three consecutive meetings. The venue of each meeting changes to locations around the world to accommodate the global membership of the committee. Individual companies can send as many representatives as they wish, so the voting process tends to favor large companies who can afford to send numbers of representatives to consecutive meetings. Because, industry consortia are generally more focused around the goal of the standard being created, the voting process is usually on a one-company-one-vote basis. Again because the goals of the standard process are tightly focused, the standards setting process proceeds rapidly to conclusion.

*Are There Standards
Truly Relevant to the
Wireless LAN User?*

From the preceding sections it is clear that there are a number of standards from a number of sources that impact the WLAN market and the users choice of WLAN products. The question arises as to which standards are of importance in the selection of a WLAN product. At the highest level, compliance to the requirements of the governmental regulatory agencies is a legal requirement for the sale and use of a WLAN product. In common with its competitors, RadioLAN products are fully compliant with all the unintended emissions requirement of Part 15 of the Code of Federal Regulations. RadioLAN has the only products available at the present time approved under the new U-NII sections of Part 15.407. In the European Union, ETSI I-ETS 300 440 governs operation of Low Power Devices, RadioLAN products have been accepted as compliant with this standard.

Reflecting back to the original intent of the standards setting process, interoperability and interchangeability among products from different vendors, it would seem that the IEEE 802.11 WLAN standard is the most relevant standard. Unfortunately, the 802.11 standard offers three different PHY implementations: Frequency Hopping Spread Spectrum, Direct Sequence Spread Spectrum and Infrared. Since the FHSS, DSSS and Infrared systems are fundamentally incompatible, the three classes of 802.11 compliant product cannot interoperate. Extreme generality was built into the 802.11 standard because of the requirement of handling a wide variety of potential applications visualized by the standard's creators. This generality has made it very difficult for manufacturers of 2.4 GHz WLAN product to configure products to demonstrate interoperability. Interoperability trials for FHSS 802.11 products have been held on a regular basis at the Wireless Interoperability Laboratory at the University of New Hampshire since late in 1997. While minimal interoperability in the sense of ability to transfer data packets from one vendor's product to another's has been demonstrated, the ability to seamlessly construct a network with products from multiple vendors has proven elusive. The DSSS vendors have fared only slightly better. With time and maturity of products the goal of true interchangeability may be reached for 2.4 GHz products, but that time is not yet at hand. Further, there seems no urgency among the 2.4 GHz vendors that their products interoperate.

If the existing WLAN standards cannot guarantee interoperability among products from various vendors, can products from different standards coexist in the same bands? Again the answer is no. The presence of a FHSS 802.11 network operating in the vicinity of a DSSS network will degrade the performance of the DSSS network.[1] The emerging HomeRF 2.4 GHz standard will interfere with a 802.11 FHSS network. Bluetooth products are now thought to be especially disruptive to DSSS products, in particular to the new generation of 802.11 High Data Rate 2.4 GHz DSSS products. Recently published simulations indicate that a busy Bluetooth network co-located with an

802.11 High Data Rate network will reduce the throughput of the 802.11 network by about 45% under the most optimistic assumptions.[2] There are also several proprietary FHSS WLAN products currently operating in the 2.4 GHz band which can interfere with other FHSS products as well as DSSS systems. However serious the problem is today, the increasing utilization of the 2.4 GHz band will only increase the severity of the problem.

If the current 802.11 WLAN standard cannot offer the degree of interoperability that will allow WLAN users to “mix and match” equipment from different vendors or ensure coexistence with other similar WLAN products, how does the WLAN customer select a WLAN solution that will protect the value of the investment? First by making sure that chosen WLAN product fully supports all the networking standards to make the wireless network fully compatible with the wired network to which it may be attached. These standards include 802.3, the Ethernet standard and 802.1d (spanning tree) and the new extensions to 802.1 (802.1p and 802.1q) that will support IP-based priority queuing and IP-based Virtual LAN.

References:

- [1] Harris Semiconductor, *Using the PRISM™ Chip Set for Low Data Rate Applications*, AN9614.1; January 1997
- [2] Zyren, James; *Extension of Bluetooth and 802.11 Direct Sequence Interference Model*; IEEE Document IEEE 802.11-98/373, November 1998