The Status and Future of 802.11-Based WLANs

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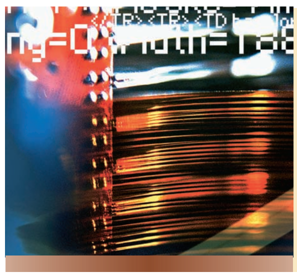
Today's wireless local area networks are designed to support mobile computing in small areas such as a building, park, airport, or office complex. The IEEE 802.11 standard (http://grouper.ieee.org/groups/802/11/index.html) defines both an *infrastructure* mode, with at least one central access point connected to a wired network, and an *ad hoc* or *peer-to-peer* mode, in which a set of wireless stations communicate directly with one another without needing a central access point or wired network connection.

The main attraction of WLANs is their flexibility. They can extend access to local area networks, such as corporate intranets, as well as support broadband access to the Internet—particularly at "hot spots," public venues where people tend to gather. WLANs can provide quick, easy wireless connectivity to computers, machinery, or systems in a local environment where a fixed communications infrastructure does not exist or where such access is not permitted. These hosts can be stationary, handheld, or even mounted on a moving vehicle.

Bandwidth considerations have thus far been secondary in WLAN design and implementation: The original 802.11 standard allowed a maximum channel bit rate of only 2 megabits per second, while the current 802.11b standard—commonly known as Wi-Fi (for "wireless fidelity")—supports an 11-Mbps maximum rate. However, the widespread deployment of 802.11a and 802.11g standards, which allow a bit rate of up to 54 Mbps, will pave the way for new types of mobile applications, including m-commerce transactions and location-based services.



Many obstacles remain to the widespread deployment of wireless local area networks.

MULTIPLE STANDARDS

As Table 1 shows, there are a number of IEEE 802.11 standards. One major problem is spectrum availability. The industrial, scientific, and medical (ISM) bands have always been the first choice, with 802.11, 802.11b, and the emerging 802.11g standard all sharing the 2.4-GHz radio band. However, because ISM frequencies are designated for unlicensed commercial use, users can experience significant interference in some locations from ambulances, police cars, taxicabs, and citizen's band radios as well as from other users and many household and office devices operating in ISM bands.

The demand for higher bit rates has led to the consideration of wider as well as less crowded bands for WLANs. IEEE 802.11a, for example, uses the 5-GHz band, but because all other working versions of 802.11 use the 2.4-GHz band, backward compatibility is an issue.

Dual-band LAN adapters that allow access to both 802.11a and 802.11b are one possible solution but are not widespread. IEEE 802.11g, which is expected to become a standard later this year, will be somewhat compatible with 802.11b—it uses the same 2.4-GHz band and provides the higher bit rates of 802.11a, but has a different transmission method. Many vendors, including Apple, are already offering 802.11g-based systems.

The choice of spectrum likewise affects power requirements and range. For example, 802.11a signals would require significantly more power than 2.4-GHz WLANs to cover the same hot spot; using the same amount of power, they would need more access points, which may not be economically feasible for some carriers. Many physical layer enhancements—including coding, better antenna design, and energy-efficient LAN protocols—can reduce, but not eliminate, power requirements at higher frequencies.

The IEEE 802.11 standard allowed three different ways to transmit data over the wireless channel—frequency hopping spread spectrum (FHSS), digital sequence spread spectrum (DSSS), and infrared—but other versions have focused on a single method of transmission. For example, 802.11b only allows DSSS, while 802.11a uses orthogonal frequency division multiplexing (OFDM), a technique that uses up to 52 carriers to transmit data from

Table 1. IEEE 802.11 WLAN standards.

Standard	Spectrum	Maximum physical rate	Layer 3 data rate	Transmission	Compatible with	Major disadvantage	Major advantage(s)
802.11	2.4 GHz	2 Mbps	1.2 Mbps	FHSS/DSSS	None	Limited bit rate	Higher range
802.11a	5.0 GHz	54 Mbps	32 Mbps	OFDM	None	Smallest range of all 802.11 standards	Higher bit rate in less-crowded spectrum
802.11b	2.4 GHz	11 Mbps	6-7 Mbps	DSSS	802.11	Bit rate too low for many emerging applications	Widely deployed; higher range
802.11g	2.4 GHz	54 Mbps	32 Mbps	OFDM	802.11/ 802.11b	Limited number of colocated WLANs due to narrow spectrum	Higher bit rate in 2.4-GHz spectrum higher range than 802.11a

a single source to achieve a 54-Mbps channel bit rate.

In addition to multiple 802.11 standards, there are other standards for WLANs such as the European HiperLAN2. Although designed for similar environments, these standards differ in frequency, bit rates, power requirements, and coverage.

HOT SPOTS

A major appeal of WLANs is that network access providers can quickly deploy them in areas with a high volume of users or network traffic and where the traditional wireless carriers have not been able to keep up with public demand for broadband Internet access.

Possible architectures

As Figure 1 shows, network access providers can deploy WLANs in hot spots in two ways. A pure WLAN-to-Internet architecture uses multiple access points backboned by fiber or wireless links to the Internet, without going through cellular or PCS (personal communications service) providers. With this approach, all WLANs connect through a central point, or a group of colocated WLANs directly link to other WLANs. If location management is required, then location accuracy is equal to one access point coverage.

Alternatively, WLANs can support handoffs to other wireless networks, and all networks connect to the Internet. For example, m-commerce applications with certain quality-of-service or real-time requirements can switch to cellular, PCS, or third-generation networks. Similarly, base stations can hand off broadcast or multicast applications to satellite-based networks, with some outdoor restrictions. This handoff can also be implemented to support atomic transactions. Location management accuracy is higher due to Enhanced 911 and other precise schemes deployed in other wireless networks that can be used in this environment.

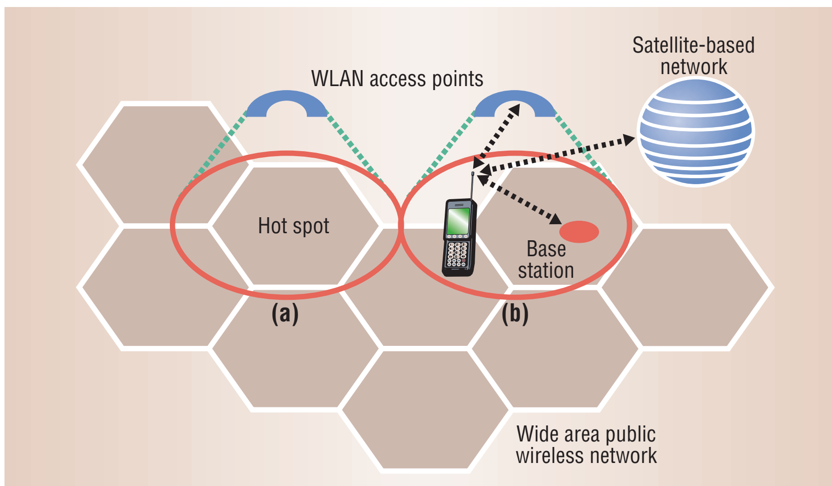


Figure 1. WLAN deployment alternatives. (a) WLANs with multiple access points are backboned by fiber or wireless links to the Internet. (b) WLANs support handoffs to other overlapping wireless networks, and all networks connect to the Internet.

Current deployment

Several thousand hot spots have already been identified throughout the world, and the number is expected to increase significantly over the next several years. Dozens of start-up hot spot operators (HSOs) have installed Wi-Fi access points at hotels, airports, restaurants, bookstores, schools, theaters, convention centers, health clubs, and other public venues. TeleSea Wireless Services even offers a broadband link to seaborne travelers within 30 miles of select US coastal access points.

Major wireless carriers are now entering the WLAN connectivity business and, due to their nationwide coverage and extensive customer base, figure to play a dominant future role. T-Mobile offers 802.11b-based access for more than half of the hot spots in the United States, with tens of thousands of mobile users accessing the Internet from its WLANs.

Cometa Networks—an HSO backed by AT&T Wireless, IBM, and Intel—recently announced an ambitious plan with iPass to set up 20,000 hot spots within the next two years. About the same time, Toshiba America Information Systems revealed that it was partnering with Accenture to deploy more than 10,000 WLANs in hot spots by year's end. Sprint PCS has also thrown its hat in the ring.

Many cities currently offer or plan to offer public broadband services to promote business and tourism. For example, Long Beach, California, offers free Wi-Fi access in its Downtown Wireless Internet District. Users access the system through a special portal that also features links to local businesses and entertainment venues, a real-time events calendar, and a searchable community database.

A number of retail vendors likewise offer WLAN access to increase sales and promote their products and services. For example, Starbucks provides T-Mobile HotSpot service to its customers at more than 1,000 of its US coffee shops. Borders offers a similar service at several hundred of its bookstores and cafes.

This past March, McDonald's began a trial program in New York City that offers an hour of free, "Intel-verified" WLAN access to customers who purchase certain combo meals, with the option to purchase a 60-minute session for a nominal fee. Unlike many other retailers, McDonald's is providing an open network for all wireless users so that customers do not have to set up an account.

CHALLENGES

Before widely deploying public WLANs, wireless carriers and service providers must overcome 802.11-related security flaws as well as the lack of multicast and location management support, which many emerging applications require. More work is also necessary to address WLAN scalability.

There must be limits to the number of different WLANs in the same area.

Security

The Wi-Fi Alliance (www.wi-fizone.org) has been working to provide a security solution, known as Wi-Fi Protected Access, until the IEEE's Task Group i completes its work on a revised security standard (802.11i) later this year or early next year. Key WPA elements include an IEEE-ratified enhanced authentication scheme (802.11x), the temporal key integrity protocol (TKIP), and the counter mode with CBC MAC protocol.

TKIP is a patch for legacy 802.11 implementations designed to correct vulnerabilities in the wired equivalent privacy protocol, particularly the reuse of encryption keys. It adds a 64-bit message integrity check, an extended initialization vector with packet sequencing, a rekeying mechanism, and per-packet key mixing in addition to 128-bit data encryption. The CBC MAC protocol uses the stronger Advanced Encryption Standard, but AES requires hardware up-grading and is not backward compatible.

Another solution uses virtual private networks with an IP security protocol tunnel. This approach would allow secure and continued access, but because a VPN gateway must process all traffic, there are inherent limitations in the number of users it could support.

Multicast support

Many emerging mobile applications—including m-commerce, distance education, and interactive games—require support for group communication. Wireless multicast is the most efficient way to update membership information for network traffic routing as mobile users move to different locations or leave the group, or as new users join the group. However, ensuring reliability, privacy, quality of service, and low delay (for real-time multicast) in WLANs are major technical challenges.

To support group-oriented mobile services, it is first necessary to identify the multicast requirements of various mobile services, modify network protocols to support multicast at higher layers, and model and evaluate the overhead due to protocol modifications. Such protocols must explicitly support all-or-nothing transactions as well as determine what to do when a user experiences brief disconnectivity or intermittent connectivity.

Location management support

One way to attract more mobile users to WLANs is to provide location-based services that personalize the user's experience. Wireless carriers could leverage a major asset—the position of subscribers within range of a given access point or base station—to support location-based billing, information services (such as providing a user with a list of nearby restaurants or movie show times), emergency services, and tracking services.

To increase location accuracy, these carriers could deploy multiple smaller access points, integrate sensors and radio frequency identification tags with WLANs, and use other wireless networks that support location management.

Scalability

The large-scale deployment of WLANs presents technical as well as economic challenges. As multiple, sometimes conflicting network access providers set up more WLANs in hot spots, interference and quality of service will become problematic. It is clear that some type of coordination must occur to limit the number of different WLANs in the same area. Toward this end, the Wi-Fi Alliance has certified numerous "Wi-Fi zones" around the world where wireless providers who charge an access fee meet its strict deployment and service requirements.

The hot spot market's viability is also uncertain. Can HSOs survive on their own or does it make more sense to merge or interoperate with wide area cellular and PCS networks? As the major wireless carriers enter the market, HSOs will face increasing pressure to reduce or even eliminate access fees. In addition to offering a broadband connection, companies such as T-Mobile have the resources to provide various service packages as well as a common bill for WLAN and traditional wireless network access.

The future of WLANs generally looks bright, but many technological and business-related hurdles remain. For widespread deployment to occur, wireless carriers and network access providers must meet consumer demands for easier access, better quality of service, more network management tools, and flexible pricing—for example, the option to be charged per transaction rather than for the duration of a connection as is currently the case.

In addition, the bit rate per user must be increased to support higher-end applications, such as wireless streaming media and videoconferencing, in WLANs. To address this problem, the IEEE 802 High Throughput Task Group—soon to become 802.11n—is exploring ways to increase bit rates to 108 Mbps and, possibly by 2005, 320 Mbps. ■

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