

# Unit 1: Wireless Network Technology

The changes in wireless technology for data networks over the past five years have been more dramatic than the changes in radio itself in the century since Guglielmo Marconi sent the first telegraph signal across the Atlantic from Cornwall in the U.K. to St. Johns, Newfoundland, on December 12, 1901. The progress in commercial radio transmission from telegraphy to voice to television was measured in decades. Commercial digital wireless transmission began in the mid-1990s when cellular digital telephony—known as PCS for Personal Communications Service—replaced advanced mobile phone service (AMPS), the then dominant analog voice transmission protocol. Digital wireless telephony technology was then split into two competing technologies: time division multiple access (TDMA) and code division multiple access (CDMA). TDMA is still used by AT&T but is being phased out in favor of global system mobile (GSM), a standard version of TDMA used by most European and Asian carriers as well as by T-Mobile and AT&T. CDMA is used by some Japanese carriers as well as by Sprint and Verizon. TDMA, GSM, and CDMA are not interoperable.

The wireless local area network (LAN) began to emerge in the late 1990s, when it became obvious that there was a need for wireless data networking. Wireless LANs required faster data transmission than was possible with cellular PCS (of any technology), and eventually industry settled upon using digital spread spectrum as defined by the IEEE 802.11 standards. Spread spectrum was originally developed for the U.S. military so wireless transmissions could be made in the presence of strong jamming signals. This work by the military was based on the spread spectrum patent US 2,292,387, which had origi-

nally been granted to Hollywood actress Hedy Lamarr and her partner George Antheil.

Frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS), both operating up to 2.0 Mbps, were the first two IEEE 802.11 technologies. Neither is commercially available today. These initial technologies were improved upon until, in rapid succession, IEEE 802.11b (operating at up to 11 Mbps) and 802.11a and 802.11g (both operating up to 54 Mbps) emerged. All of these are called Wi-Fi (wireless fidelity) after the name of the supporting industry association, the Wi-Fi Alliance, but 802.11b has become a commercially successful technology with a large installed base. Both 802.11a and 802.11g are rapidly penetrating the market, essentially displacing 802.11b. For the sake of simplicity, I will continue using 802.11a, 802.11b, and 802.11g to designate each of the IEEE 802 standards, but the marketplace calls these technologies *Wireless-A*, *Wireless-B*, and *Wireless-G*, respectively.

## 1.1 Standards

The dynamic nature of wireless digital data communications stems from the standards committees of the Institute of Electrical and Electronic Engineers (IEEE), which develops most of these protocols. No illusion currently exists in the IEEE 802 committee that is responsible for personal area network (PAN), LAN (local area network), MAN (metropolitan area network), and WAN (wide area network) that it will be possible to create a single network protocol useful over all of these four domains. Therefore, each application that has a special interest that is not accommodated by an existing protocol can form a new sub-committee to create a new protocol. IEEE ensures only that these committees deliberate fairly, do not exclude a genuine interest, and that all proposed standards are publicly reviewed. All IEEE 802 standards are automatically submitted to the ISO/IEC (International Organization for Standardization and International Electrotechnical Commission) for consideration as international standards. Several of the IEEE 802 standards have failed in the commercial marketplace, while others have succeeded.

Another source of wireless communications protocols is the International Telecommunications Union (ITU), the standards body for telephone networks. With the conversion of telephony from a purely wired circuit-switched analog service—also known as POTS (plain old telephone service) – to 3G (third-generation) wireless, a technology convergence is underway in data networks. 3G is a wireless packet-switched digital service based on CDMA, and is an ITU standard now being commercialized in several countries with worldwide adoption was scheduled by 2005, but continued popularity of GSM has delayed implementation in most countries. In fact, many have predicted that home and mobile computing will soon use broadband wireless packet switching rather than either telephone DSL (digital subscriber loop) or CATV (community antenna television) cable modem services. Even though there are excellent reasons to keep 3G wireless in mind for in-plant voice networks and some mobile data applications, it is not presently being considered for industrial use. However, given the eventual availability of low-cost and low-power-consumption 3G, and the likely successor, 4G, it cannot be ignored.

A word of caution is in order about the standards documents for data communications. These very large documents are not intended to be read by users. They are written for the implementer of networks and networking devices. If you really want to see some examples of such standards, however, most IEEE 802 network documents more than six months old are available for download on the IEEE standards web site:

<http://standards.ieee.org/getieee802/> (look for the *click here* link in the last paragraph of the text). The IEEE and others often publish books about the standards, making them easier to understand.

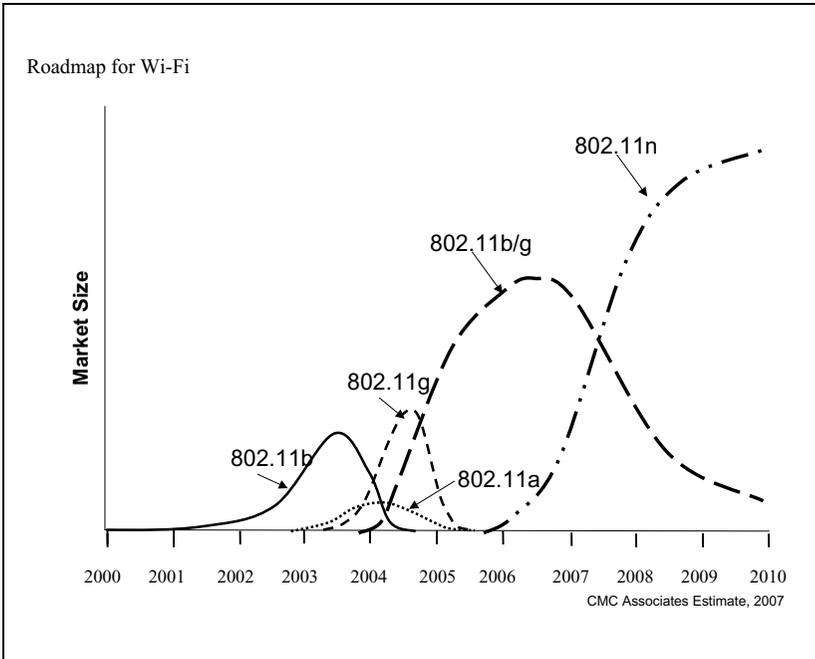
### 1.1.1 Wi-Fi

One factor causing rapid technological change in wireless communications is the ever-increasing capacity of commercial semiconductor processes such as CMOS (complementary metal oxide semiconductor) to handle higher frequencies. This factor alone is responsible for the recent rise in interest in

802.11a, which previously required more expensive GaAs (gallium arsenide) processes or higher-power bipolar semiconductors. When 802.11a parts are built in CMOS, they are as economical as the slower 802.11b parts.

With the ratification of 802.11g and the subsequent flood of new products on the market, we are now witnessing another dramatic change in the Wi-Fi market. It seems certain that by mid-2004 802.11g, which is backwards-compatible with 802.11b, has completely displaced 802.11b in the new wireless products marketplace. Since 802.11a and 802.11g share a common modulation technology—namely, orthogonal frequency division multiplexing (OFDM)—products that offer both standards are not only possible but also economical. As the Wi-Fi band at 2.4 GHz becomes saturated, the benefits of 802.11a become compelling since the 5.0 GHz band currently used for 802.11a offers eleven non-overlapping channels, versus three for 802.11b and 802.11g. A recent FCC regulation makes thirteen additional channels available for 802.11a, for a total of twenty-four non-overlapping channels. Chips that offer 802.11a/b/g are already on the market, and soon all new Wi-Fi LANs will offer all three technologies at little to no price premium. Figure 1 illustrates a roadmap for this transition in the Wi-Fi market.

IEEE 802.11n is nearing completion as a standard; however, the specification in draft form has long been available. Many suppliers have now released “pre-n” products promising to upgrade them when the final standard is finally approved. The most appealing technology embedded into 802.11n is called MIMO (Multiple Inputs, Multiple Outputs) most easily recognized by several antennas on 802.11n products. The “n” standard calls for all signals to be simultaneously transmitted on each of the antennas. Due to the spatial diversity of these antennas (they are a few centimeters apart,) signals transmitted by all antennas will be received by the multiple antennas of the receiver slightly out of phase with each other. MIMO technology provides a way for the receiver to align the phases of the received signals such that the resulting resolved signal is now stronger and more reliable than any single signal. Note also



**Figure 1. Roadmap for Wi-Fi**

that reflected signals, often called multipath signals, are also out of phase with the original. MIMO offers a technical solution to the multipath “problem” often associated with networks built in the “canyons of steel” that often describe large plant units in the process and metals industries.

Additionally, IEEE 802.11n also bonds channels in both the 2.4 and 5 GHz ISM bands that were formerly assigned to 802.11g and 802.11a. This means that currently, an IEEE 802.11n device requires two radios, one for each band. In the future, a single software-defined radio may be able to solve this same problem. Many inexpensive “pre-n” devices may not be able to implement the dual radio part of IEEE 802.11n simply because they do not have a 5 GHz radio.

Channel bonding in 802.11n may be used to achieve a higher data rate. While a single channel for either a or g can achieve a theoretical 54 Mbps, bonding two channels can achieve a theo-

retical 108 Mbps. 802.11n can achieve data rates as high as 480 Mbps by bonding nine channels.

The Wi-Fi market is supported by The Wi-Fi Alliance, which in its own words is *“is a nonprofit international association formed in 1999 to certify interoperability of wireless Local Area Network products based on IEEE 802.11 specification. Currently the Wi-Fi Alliance has over 200 member companies from around the world, and over 1000 products have received Wi-Fi® certification since certification began in March of 2000. The goal of the Wi-Fi Alliance’s members is to enhance the user experience through product interoperability.”* The Wi-Fi Alliance website is <http://www.weca.net/OpenSection/index.asp>.

### 1.1.2 Bluetooth

Bluetooth has already been applied in many commercial products but at a much slower pace than its developers ever dreamed. Originally defined to replace wire/cable technology for cellular telephony, such as for connecting headsets, it had just enough networking capability to interest a wide variety of companies to extend its use beyond its original scope. In fact, Bluetooth is far more than a communications protocol; it is a full communications application stack. The lower two communications layers of Bluetooth (PHY and MAC) have been published as the IEEE standard 802.15.1. For the original task of device connection, Bluetooth offers a rich suite of functionalities, including enabling walk-up linking without user interaction and establishing voice connection. Bluetooth networking is intentionally limited to a maximum of eight Bluetooth nodes, which together form a piconet. When a node is included in more than one piconet, that node then assumes the routing task of forwarding messages to/from the other piconet, adding a form of mesh networking to the complexity of Bluetooth. The most attractive feature of Bluetooth for industrial automation purposes is its use of forward error correction (FEC) for delivering messages without error and without requiring retransmission. The drawback of FEC is loss of efficiency: a 1 Mbps communications channel can deliver only 721 Kbps.

A multivendor consortium defined Bluetooth, not a standards organization. With consent of the Bluetooth Alliance, the lower two layers of Bluetooth were reformatted and have now become the IEEE 802.15.1 standard. Just like 802.11b and 802.11g, it operates in the unlicensed 2.4 GHz frequency band, but uses frequency-hopping spread-spectrum technology that hops faster than the original FHSS of 802.11. As a result, the presence of Bluetooth in close proximity to Wi-Fi nodes causes the signal for the WLAN to degrade, sometimes spelling disaster for Wi-Fi transmissions. Bluetooth 1.2 and later protocols help such nodes avoid signal degradation by listening for signals on the radio channels before transmitting. Many early suppliers of nodes with both Bluetooth and Wi-Fi have been able to synchronize transmissions to avoid degradation. Suppliers of 802.11a, which operates in the 5 GHz unlicensed band, are quick to point out that they avoid signal degradation from Bluetooth completely. Nevertheless, 802.11g suffers the same potential problems as 802.11b in the presence of Bluetooth.

If you want to know more about Bluetooth, a rich source of information can be found on the official Bluetooth SIG website: <http://www.bluetooth.com/help/>. If you want to develop Bluetooth products, the Bluetooth developers' website offers lots of reference material and discussion groups: <https://www.bluetooth.org/>.

## 1.2 Proprietary or Non-Standard Wireless Networks

Standards take a long time to be developed, much slower than the pace of technology. Commercial suppliers often cannot wait for the approval of a standard, or may have a product concept that adequately fulfills the network requirements more than any proposed standard. These companies will often introduce their network products hoping to establish a market in the absence of standardized networks. The experience gained by these suppliers can often be highly useful to the designers of network standards. Sometimes, this network can become a standard.