IEEE 802.11 has captured the support of major wireless industry leaders. The growth and commercialization seen by the personal communications sector may be finally spilling over to the Wireless LAN sector, but I still remember the cold and stormy night back in 88 when I started working on a Wireless LAN at a start-up. That venture didn’t work, but it did provide valuable insight into the problems and necessary test tools needed for wireless.

The current project at Berkeley Varitronics Systems (BVS) to develop a test instrument for IEEE 802.11 is another testament that the Wireless LAN may finally be realizing some of its potential. This article will present several challenges to Wireless LAN design, how they were solved at the start-up, how IEEE 802.11 addresses them and necessary test tools. Considered here is direct sequence spread spectrum system (DSSS) specified in 802.11. 802.11 also specifies a frequency hopping spread spectrum system (FHSS).

**Architecture and Protocol**
IEEE 802.11 does allow for peer to peer communication, but this is typically utilized for small temporary networking between a few computers or devices. A large LAN will utilize a network with several access points (AP) s. All mobile stations (peers) communicate with an AP. The AP provides a connection to a wired LAN and is the local radio relay to the mobile stations. In this type of network, mobile stations are not required to communicate with each another. If one mobile station sends data to another, it must send the data to the AP, and the AP sends the data to the second mobile station. This doubles the bandwidth required to transmit the data, but it greatly reduces the required performance of the RF link. Instead of requiring each mobile station to have enough power and good antenna position to all the other mobile stations, it must only communicate with the AP. See figure 1.

As experienced with the start-up back in 88, mobile to mobile station communication is a real hardship. Transmit power requirements are increased and the positioning of antennas, without diversity, becomes virtually impossible. Indoor multipath is severe and interactive. Positioning an antenna for good performance between two mobile stations will undoubtedly disturb performance to another mobile station. Of course, antenna diversity can improve this situation, but peer to peer radio links are still a hardship.

At the start-up, unfortunately a token passing LAN architecture where every station was required to receive the token as it was passed around the network was used. If a single station lost the token, the network would be re-synced and throughput would drop. Positioning antennas so that every station could receive from each other was virtually impossible. The token passing protocol was not the right thing for a Wireless connection, but it was an off-the-self solution. A new protocol for wireless was only a dream, but creating the communications link was the main focus.

A novel solution to work with the mobile to mobile token passing was designed, which led to a patent. Mobile stations communicate to an AP on frequency 1, and the AP re-transmits the message to the other mobile stations at frequency 2. In this way, each
mobile station could aim its directive antenna at the AP. This type of architecture proved valuable for mobile to mobile communication when it is required.

Multipath

Multipath is a major problem. Reflections in the indoor environment can be quite severe. Moving an antenna slightly or an object in the room can drastically change the signal at the mobile station. Reflections combine at the receiver's antenna and may do so constructively or destructively. Multipath that is greater than 1 chip apart may be combined with a RAKE receiver or an equalizer may be used to correct for the multipath.

Digitally modulated RF signals manifest unique characteristics in the presence of reflections. These reflections cause unphased additions of data symbols that result in bit errors. Simple signal strength measurements (envelope detectors measuring narrow bandwidth signals such as CW) are deceiving because the signal may measure strong, but when digitally modulated, the Bit Error Rate (BER) can be surprisingly poor. Multipath reflections (also known as time dispersion) of the RF carrier is when two or more signals of the same origin arrive at the receive antenna delayed in time because they traveled different path lengths or because of reflections and scattering in the propagation environment. This deterioration of the signal must be considered especially when planning an indoor radio system.
Figure 3 shows three distinct multipath components each about a chip apart that were recorded with a BVS Duet™ multipath analyzer. When the receiver's code generator is aligned in time with a multipath component, the receiver's correlator produces a response. This multipath can be minimized with the use of a RAKE receiver that demodulates each multipath and combines them with an equalizer. This does add cost and complexity to the wireless LAN's receiver.

Multipath that is less than a chip apart can combine destructively and severely degrade system performance. At the start-up, multipath proved to be one of the most troublesome problems. We depended on aiming directive antennas at the AP to combat multipath.

802.11 specifies equalizers, RAKEs and antenna diversity to combat multipath.

**Microwave Ovens**

The 2.4 GHz ISM band is the microwave oven band! The interference emitted by a microwave oven sweeps over tens of megahertz and is synchronous with the 60 Hz AC line frequency. The half-wave rectified power to the magnetron pulses it on for 8 msec and off for 8 msec. The power emitted by microwave ovens was observed to be quite strong, and it was typically received with more power than the power from the AP. The 802.11 packet length was chosen to operate between the pulses of the microwave oven.

**Data Rates and Signal Acquisition**
When designing a Wireless LAN, faster always seems better. The design was started with 32 chips per symbol. With pressure to increase the throughput of the LAN, the processing gain was reduced and the symbol rate increased by changing the number of chips per symbol to 13 chips. This is very similar to the 11 bit Barker code used for the 1 and 2 Mbps systems in the 802.11 specifications. There are minimum processing gains required by FCC regulations to operate in the ISM band, but when does the DSSS system stop and a traditional QPSK radio start? The 11 bit Barker code has terrific correlation properties that make it easy to detect even in the presence of strong interferences, other operating devices and multipath that is greater than 1 chip apart. The correlation property not only gives a gain in demodulation, but it enables the receiver to find, track and separate the signal of interest from other signals.

The 11 Mbps 802.11 extension is 5.5 times the rate of the original QPSK 2 Mbps. This apparently gives 2 chips per data bit. A spreading code that is only 2 chips not only gives very small processing gain, but is not much to acquire, track or demodulate in the presence of interfering signals and multipath. Such a system would be limited to demodulating the strongest signal, which is not necessarily the signal of interest.

The 802.11 extension uses a variation of m-ary orthogonal keying (MOK) modulation. Complex symbols are modulated onto the I and Q phases of the QPSK transmitter. These complex symbols have good orthogonal properties (they don’t interfere with each other) and good correlation properties. Figure 4 illustrates the encoding process.

FIGURE 4 — MOK Modulation 802.11 Extension

Data Rate=8 bits/symbol * 1.375 MSps=11MBps
With this type of encoding, correlators can be built that correlate against the different 64 bit codes. The correlator will respond when it is time aligned with a multipath component. This efficient type of encoding can separate multipath components and be used to acquire, track and demodulate the signal. The 802.11 extension does not have the same amount of processing gain, and the range of the extension is limited to about 30 meters. The original 802.11 s range is limited to about 100 meters under the same propagation conditions.

**Test Instruments**

Berkeley Varitronics Systems is designing test tools for 802.11 LANs. These tools have signal strength detection both before and after the processing gain. Signal strength before the processing gain sweeps across the frequency band and detects the power in a relatively narrow bandwidth. A peak hold mode detects and displays narrow band interferes such as microwave ovens and frequency hopping systems. The signal strength detection after correlation includes the effects of multipath. The combination of these two measurements combined with portability will aid in the planning and optimization of 802.11 wireless systems.

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