OFDM carries the future of wireless networking

Whether selecting chipsets for access points or mobile devices, an understanding of OFDM is essential

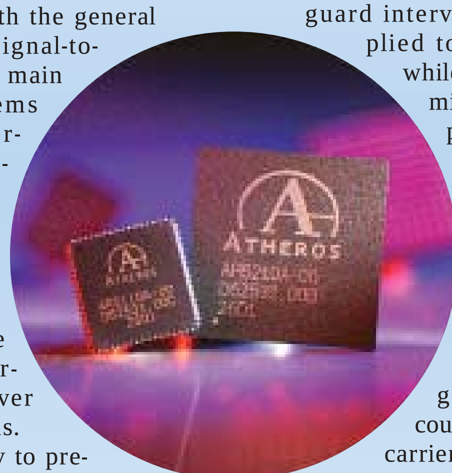
BY BILL MCFARLAND
Atheros Communications
Sunnyvale, CA
http://www.atheros.com

The robust high-bandwidth capabilities of orthogonal frequency division multiplexing (OFDM) confer immediate advantages on wireless products that can take advantage of it—and many types of networking systems are doing so. OFDM underlies the existing IEEE 802.11a wireless LAN (WLAN) standard and the proposed IEEE 802.11g WLAN standard, as well as digital cable, DSL, digital TV, and power-line networking products. OFDM is also being considered for use in 4G cellular systems.

The reasons for this widespread interest become clear from a glance at OFDM characteristics. In 802.11a, OFDM provides raw data rates up to 54 Mbits/s in a 20-MHz channel. In addition to supporting high data capacity and resisting degradation from various types of radio effects, OFDM makes highly efficient use of the available spectrum. The latter characteristic will become crucial in coming years as wireless networks are built out, especially in enterprise environments.

Managing imperfect airwaves

All wireless systems have to deal with the many unruly ways in which radio signals behave in the real world. Along with the general challenges of signal-to-noise ratio, the main types of problems are self-interference (intersymbol interference or ISI) and fading owing to multipath effects, which occur when the same signal arrives at a receiver via different paths.



The main way to prevent multipath errors is to transmit a short block of data (a symbol) then wait until all the multipath echoes fade before sending another symbol. This waiting time is often referred to as the guard interval.

The longer the guard interval, the more robust the system is in the presence of multipath effects. But during the guard interval, the system gets no use from the available spectrum. So the longer the wait, the lower the effective channel capacity.

Some guard interval is necessary for any wireless system, but the goal is to minimize that interval and maximize the symbol transmission time. OFDM meets this challenge by dividing transmissions among multiple subcarriers. The same guard interval can then be applied to each subcarrier, while the symbol transmission time is multiplied by the number of subcarriers.

Since 802.11a OFDM uses 52 subcarriers, for example, an 802.11a WLAN can afford 52 times the guard interval than a single-carrier system could. The 802.11a subcarriers are spaced 312.5-kHz apart. The symbol period is 3.2 µs plus an 800-ns guard interval.

The system thus tolerates peak multipath delays of nearly 800 ns. Compared with the 65 ns of multipath tolerance provided by many 802.11b direct sequence spread spectrum (DSSS) based products, OFDM represents a 12-plus times improvement in multipath tolerance.

Using multiple subcarriers also makes OFDM systems more robust in the presence of fading. Because fading typically decreases the received signal strength at particular frequencies, the problem affects only a few of the subcarriers at any given time. Error-correcting codes provide redundant information that enables OFDM receivers to restore the information lost in these few erroneous subcarriers.

Each of the subcarriers in an OFDM system can be modulated individually using whatever technique suits the application. In 802.11a, the choices include BPSK, QPSK, 16-QAM, and 64-QAM.

After modulation, the data from all the subcarriers are converted to a single stream of symbols for transmission. At the receiver, the stream is converted to the frequency domain via fast Fourier transform (FFT), then each "frequency bin" (subcarrier) is decoded separately.

Why orthogonal?

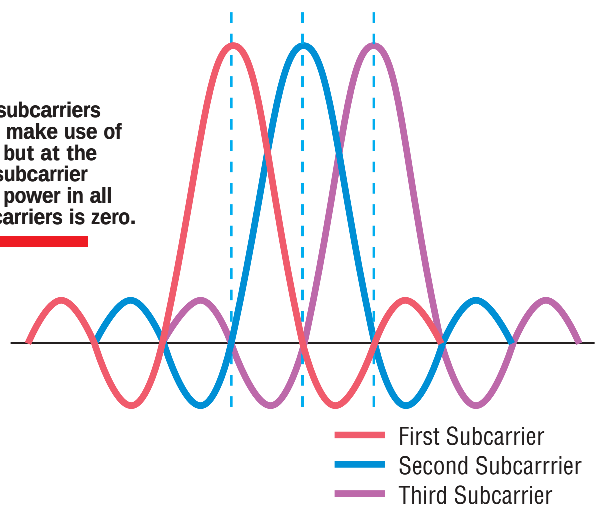
Traditionally, frequency division multiplexing (FDM) has used conventional filtering to separate subcarriers at the receiver. This approach required the insertion of significant guard bands between the subcarriers (different from the guard intervals that prevent ISI).

Making the subcarriers mathematically orthogonal was a breakthrough for OFDM because it enables OFDM receivers to separate the subcarriers via an FFT and eliminate the guard bands. As *Fig. 1* shows, OFDM subcarriers can overlap to make full use of the spectrum, but at the *peak* of each subcarrier spectrum, the power in all the other subcarriers is zero.

OFDM therefore offers higher data capacity in a given spectrum while allowing a simpler system design. Creating orthogonal subcarriers in the transmitter is easy using an inverse FFT.

To ensure that this orthogonality is maintained at the receiver (so that the subcarriers are not misaligned), the system must keep the transmitter and receiver clocks closely synchronized—within 2 parts per million in 802.11a systems. The 802.11a standard therefore dedicates four of its 52 subcarriers as pilots that enable phase-lock loops in the receiver to track the phase and frequency of the incoming signal. This method also eliminates low-frequency phase noise.

Fig. 1. OFDM subcarriers can overlap to make use of the spectrum, but at the peak of each subcarrier spectrum, the power in all the other subcarriers is zero.



Separating the subcarriers via an FFT requires about an order of magnitude fewer multiply-accumulate operations than individually filtering each carrier. In general, an FFT implementation is much simpler than the RAKE receivers used for CDMA and the decision-feedback equalizers for TDMA.

The complexity advantage of OFDM grows dramatically as the data rate increases. The complexity of the transceivers is hidden inside the chipsets that implement a particular standard, but reducing device complexity and signal-processing requirements lead to benefits customers can see. A simpler chip is more reliable and can reduce costs. Perhaps more important, the simpler circuitry helps reduce the system's power demands—a crucial advantage for mobile devices.

The wireless future

Since inexpensive and high-performance CMOS 802.11a chipsets entered the market in September 2001, the relative merits of 802.11a and 802.11b have increasingly been debated. However, 802.11a's underlying OFDM technology is easily superior to 802.11b's DSSS approach in terms of both bandwidth and robustness, so for technologists the debate has been a nonstarter.

The supporters of 802.11b have even adopted OFDM as the technology of choice for eventual successor products to 802.11b in the 2.4-GHz band. The proposed standard for these products is 802.11g.

The introduction of chipsets that support both 802.11a and 802.11b as well as the 802.11g draft standard has resolved the debate about WLAN standards. With the ability to choose any of these standards, increasing numbers of users will see the advantages of OFDM first hand. 802.11a's combination of OFDM and the interference-free 300-MHz-wide 5-GHz band are proving that the future of WLANs lies in this direction. EP