EION WIRELESS

White Paper

Wide-Band Orthogonal Frequency Multiplexing (W-OFDM) Technical

Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique whose history dates back to the mid-1960's. Although, the concept of OFDM has been around for a long time, it has recently been recognized as an excellent method for high speed bi-directional wireless data communication. The first systems using this technology were military HF radio links. Today, this technology is used in broadcast systems such as Asymmetric Digital Subscriber Line (ADSL), European Telecommunications Standard Institute (ETSI) radio (DAB:Digital Audio Broadcasting) and TV (DVB-T:Digital Video Broadcasting---Terrestrial) as well as being the proposed technique for wireless LAN standards such as ETSI Hiperlan/2 and IEEE 802.11a. There is also growing interest in using OFDM for the next generation of land mobile communication systems.

OFDM efficiently squeezes multiple modulated carriers tightly together reducing the required bandwidth but keeping the modulated signals orthogonal so they do not interfere with each other. Any digital modulation technique can be used on each carrier and different modulation techniques can be used on separate carriers. The outputs of the modulated carriers are added together before transmission. At the receiver, the modulated carriers must be separated before demodulation. The traditional method of separating the bands is to use filters, which is simply frequency division multiplexing (FDM). Fig. 1 shows a representative power spectrum for three sub-channels of a FDM system.

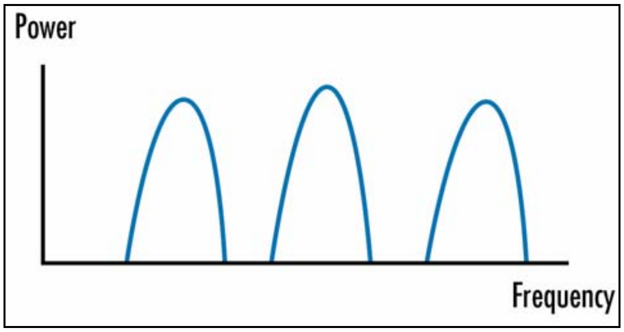

Figure 1. FDM using Filters

In a classic FDM system, the subchannels are non-orthogonal and must be separated by guard bands to avoid interchannel interference. This results in reduced spectral efficiency.

Another method to achieve frequency separation, but is more spectrally efficient than FDM is to overlap the individual carriers, yet ensuring the carriers are orthogonal is to use the discrete Fourier Transform the (DFT) as part of the modulation and demodulation schemes. This is where the name orthogonal FDM (OFDM) arises. High speed, fast Fourier transform (FFT) chips are commercially available, making the implementation of the DFT a relatively easy operation. Fig. 2 shows the spectrum of an OFDM signal with three sub-carriers. The main lobe of each carrier lies on the nulls of the other carriers. At the particular sub-carrier frequency, there is no interference from any other sub-carrier frequency and hence they are orthogonal. In Fig.2, the sub-carriers are 300 Hz apart.

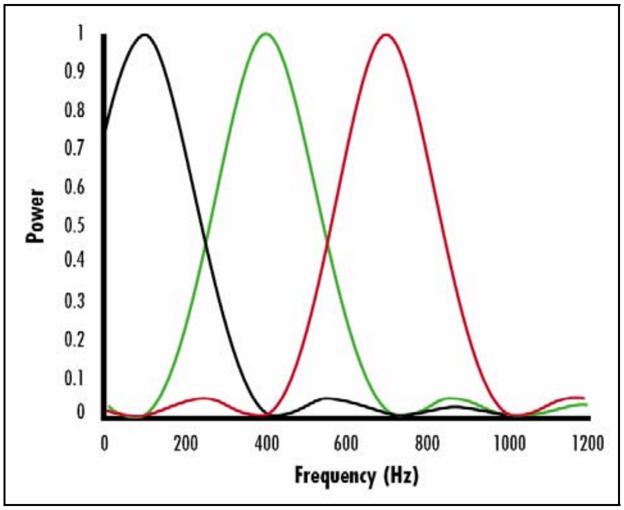

Figure 2. Spectrum of an OFDM signal with three sub-carriers.

The orthogonal nature of the OFDM subchannels allows them to be overlapped, thereby increasing the spectral tightly efficiency. In other words, as long as orthogonality is maintained, there will be no interchannel interference in an OFDM system. In any real implementation, however, several factors will cause a certain loss in orthogonality.

Designing a system which will minimize these losses therefore becomes a major technical focus.

Another advantage to OFDM is its ability to handle the effects of multipath delay spread. In any radio transmission, the channel spectral response is not flat. It has fades or nulls in the response due to reflections causing cancellation of certain frequencies at the receiver. For narrowband transmissions, if the null in the frequency response occurs at the transmission frequency then the entire signal can be lost.

Multipath delay spread can also lead to intersymbol interference. This is due to a delayed multipath signal presents overlapping with the following symbol. This problem is solved by adding a time domain guard interval to each band OFDM symbol. Intercarrier interference (ICI) can be width avoided by making the guard interval a cyclic extension of, the OFDM symbol.

There are, however, certain negatives associated with this technique. It is more sensitive to carrier frequency offset and sampling clock mismatch than single carrier systems. Also the nature of the orthogonal encoding leads to high peak-to-average ratio signals: or in other words, signals with a large dynamic range. This means that only highly linear, low efficiency RF amplifiers can be used.

We present here W-OFDM technology, which is less sensitive to inherent OFDM problems such as frequency offset, sample clock offset, phase noise and amplifier non- linearities. W-OFDM is also able to tolerate strong multipath and fast changing selective fading by using a powerful equalization scheme combined with a forward error correction scheme.

What is W-OFDM?

Wideband OFDM is a transmission scheme that is the basis of the IEEE standard 802.11a, which is the foundation of the proposed IEEE standard 802.16. It is a patented technology in the United States under patent number 5,282,222 and in Canada under patent number 2,064,975.

W-OFDM overcomes problems with multipath by sending training symbols; the adverse channel effects can then be reduced through a simple division by the channel frequency response. It also employs a spreading forward error correcting code, such as Reed-Solomon, to spread the symbols over many frequencies that convert the signal to direct sequence spread-spectrum with the ability to recover the symbols even if some carriers are totally absent. W-OFDM's efficiency and noise tolerance unite the best of spread-spectrum and narrowband systems. Recall that spread-spectrum uses excessive bandwidth to compensate for noise and multipath, while narrowband technology is more sensitive to multipath propagation.

To overcome the problems of high peak-to-average signal amplitude and fading due to multipath effects, W-OFDM incorporates signal randomization and channel estimation. Randomization of the data at the transmitter has the effect of whitening the OFDM signal and reduces the need for very linear (and hence, inefficient) radio frequency power amplifiers. By including known data in each frame of OFDM data, it is possible to compute an estimate of the transmission channel and use that estimate to correct for the effects of the channel on the data.

W-OFDM enables the implementation of low power multipoint RF networks that minimize interference with adjacent networks. This reduced interference enables independent channels to operate within the same band allowing multipoint networks and point-to-point backbone systems to be overlaid in the same frequency band.

W-OFDM System Architecture

Figure 3 shows the processing blocks with the W-OFDM modem. The network interface is the source of data bits art for the modem.

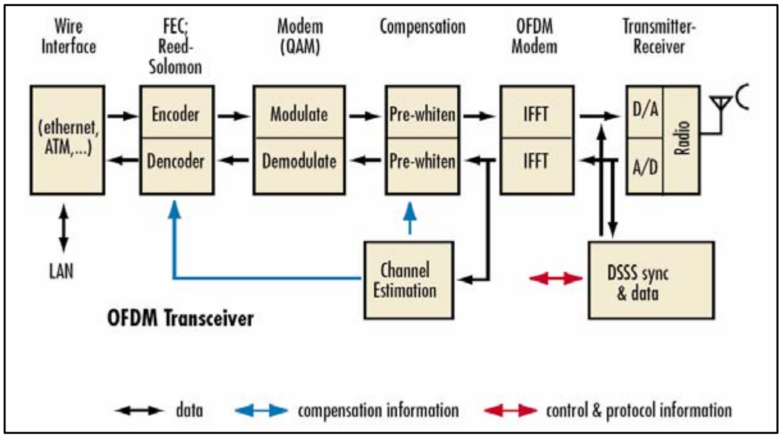

Figure 3. Block diagram of the W-OFDM transceiver.

Encoder

The encoder prepares the bits so that the decoder can correct bit errors that may occur during transmission. The bits entering the Encoder are grouped into blocks. The encoder uses the Reed-Solomon forward error correction algorithm to produce a larger block of bits. Data at 32 Mbps is sent to the Reed-Solomon encoder which takes 200 input bytes and produces a 216 byte codeword. <See Paper ‟Reed Solomon FEC for OFDM Transceiver''>

Modulator

The modulator transforms the encoded block of bits into a vector of complex values which is the W-OFDM symbol in the frequency domain. Groups of bits are mapped onto a modulation constellation producing a complex value representing a modulated carrier. The carrier representing DC is not modulated to eliminate complications with DC levels and carrier feed-through. Some carriers, called pilot carriers, are modulated with known values to allow the demodulator to adjust amplitude and phase. There are multiple pilot carriers to improve SNR and to deal with multipath where a selective fade attenuates a pilot carrier. <See Paper "Exploiting Pilot Subcarriers in OFDM Transceiver System to Augment Data Recovery">

Signal Whitener

The signal whitener reduces the peak to average power level ratio that must pass through the radio amplifiers null and A/D converters; it can also provide a level of security. The W-OFDM symbol (vector of complex values) is multiplied by a vector of complex values, R, that is known to the transmitter and receiver. All values in R have unity amplitude and phases are selected so that the average adding power level of the resulting transmitted signal varies less carrier than without this operation. There are many different guard vectors that can be used for R and a different R can be used for each W-OFDM symbol in sequence; therefore, this stage can be used as a level of security with no overhead.

Training Symbols

Six training symbols are added to the data stream. The first five symbols are used to estimate the channel transfer function, and the inverse is applied to every OFDM frame to compensate for the channel, much like equalization. The channel estimates are used to improve the error correcting capability of the RS decoder.

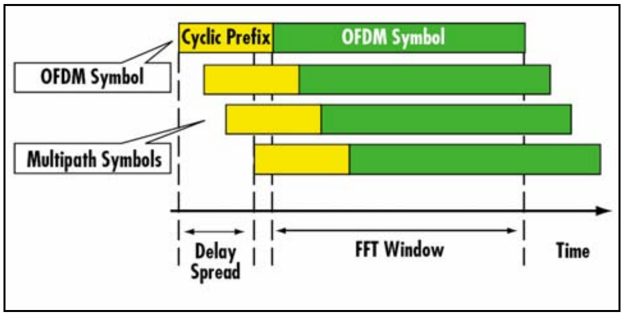

Figure 4. W-OFDM solves the problem of intersymbol interference due to multipath delays by incorporating a cyclic prefix.

IFFT

The IFFT processing block transforms the W-OFDM symbol from the frequency to the time domain. It also prepares the time domain W-OFDM symbol for transmission. The vector is scaled for maximum SNR during transmission. The vector is cyclically extended to reduce the effects of intersymbol interference at the receiver as shown in Figure 4.

FFT

The FFT processing block transforms the W-OFDM symbol from the time to the frequency domain.

Synchronization

For synchronization, a direct sequence (DS) spread spectrum signal is used. It is made up of 32 differential phase shift keying (DPSK) symbols spread by a pseudonoise (PN) sequence of 11 chips. The DS signal is and also used for automatic gain control; the OFDM receiver backbone recovers gain and frequency error information from the synchronization message. The automatic gain control processing (AGC) algorithm measures the received power level during the packet preamble as shown in Fig. 5 and adjusts the receiver gain to maximize the SNR of the received encoder signal while ensuring the signal is not distorted due to clipping.

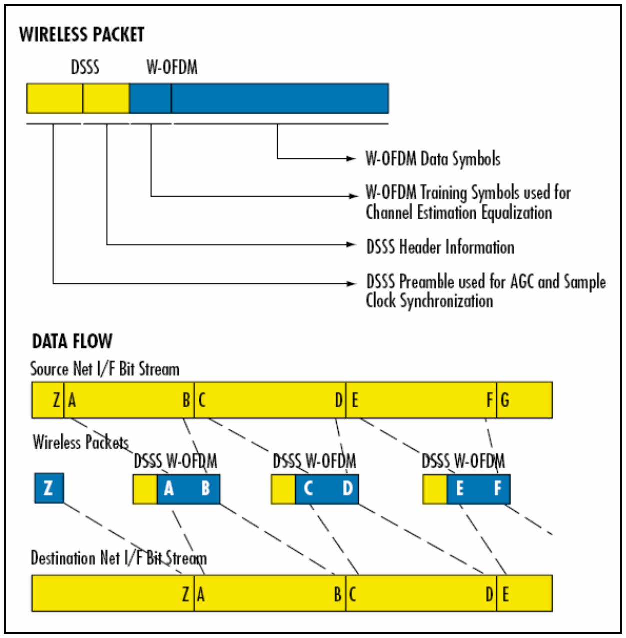

Figure 5. W-OFDM Wireless Packet structure & flow

Channel Estimation

The amplitude and phase distortion caused during transmission is determined by comparing the original known training symbol with the received W-OFDM training symbols. The comparison involves a division in the frequency domain (ie the training symbols pass through the FFT processing block). This frequency domain channel estimation, C, is combined with (multiplied by) the known pre-whitening vector R for use by the equalizer below. In addition, the decoder is informed of carriers in the vector C that are below a given threshold. This information, known as erasures, is later used by the Reed-Solomon decoder. The decoder only has to recover the values of the transmitted data; this gives the decoder the possibility of correcting more errors.

Equalizer

The equalizer removes the channel distortion and the pre-whitening. The W-OFDM vector is multiplied by the l pre-computed channel estimation.

Demodulator

The W-OFDM symbol is converted back into a block of bits. The pilot carriers that were set to known levels by the modulator are used to determine a factor used to correct the phase and amplitude of the modulated carriers. Each carrier is converted back to bits based on the constellation used for modulation.

Decoder

The decoder detects and corrects bits in error producing complex the original block of bits. The decoder is based on the Reed Solomon algorithm which uses the erasure feature to ignore bits that were on carriers with low SNR (the subcarriers below a threshold from the channel estimation vector C..

Conclusion

In this paper, we presented a W-OFDM transceiver system architecture for high-speed wireless data communication. Through the use of channel estimation and equalization by employing forward error correction, W-OFDM systems can expect a BER of approximately 1e-6 with a received signal strength of -75dBm. To improve the high peak-to-average signal problem, em W-OFDM pre-whitens the signal. A reduced Peak to Average Power ratio will result in a higher average transmitted power, which will therefore increase the overall system performance.

The Internet has been the medium that facilitates interactive, multimedia applications that require increasingly greater bandwidth capacity. The next evolution of wireless will be in data communications applications that can deliver broadband services to anyone, anytime, anywhere. With the combination of high bandwidth, spectral efficiency and increase in signal integrity, W-OFDM will open up new markets for applications.