Prolog to

Adaptive Multicarrier Modulation: A Convenient Framework for Time-Frequency Processing in Wireless Communications

An introduction to the paper by Keller and Hanzo

Multiple carriers are used to reduce intersymbol interference in high-data-rate wireless communications. The intersymbol interference takes place when echoes on different-length propagation paths result in overlapping of received symbols, hence increasing the error rates. This interference places a limit on the data rate that a wireless carrier can effectively handle. By transmitting in parallel over a set of subcarriers, using orthogonal frequency division multiplexing (OFDM), the data rate for any subcarrier can be greatly reduced. Harmonically related frequencies generated by Fourier transforms and inverse transforms are used to implement OFDM systems.

OFDM recently became the European standard for digital audio broadcasting. It is currently being developed for use in wireless asynchronous transfer mode networks and wireless local-area networks. OFDM is also applicable to electrical and optical waveguide communications. It is being used in asynchronous digital subscriber line and high-bit-rate digital subscriber line systems, and has been suggested for use in power-line communications.

A specific problem associated with OFDM is that receiving a number of superimposed subcarrier signals can result in high instantaneous signal peaks, large amplitude swings, and clipping of signal peaks by power amplifiers. This problem is being addressed by development of coding techniques designed to minimize the peak power of OFDM signals.

Another problem, and one to which Keller and Hanzo give considerable attention, is maintaining time and frequency synchronization between OFDM transmitters and receivers. Frequency mismatch can produce interference between subcarriers and result in high bit error rates. While time synchronization errors do not produce interference between subcarriers, these errors cause overlapping of adjacent symbols as they are received, and this increases the bit error rate of the system. Synchronization usually begins with an initial estimate of errors, which is followed by fine tracking to correct for small short-term deviations. The initial estimate must be accurate enough to allow for accurate tracking. The authors cite a number of techniques for initial error estimation and several tracking methods.

In order to assist the receiver in estimating the phase error, pilot tones may be transmitted. Phase information from properly spaced pilot tones can be used to determine the time misalignment of the received OFDM symbol information. Differential encoding provides another means of estimating OFDM timing errors. The differential encoding can be between corresponding subcarriers of consecutive symbols or between adjacent subcarriers of the same OFDM symbol. When a negative time shift occurs, data are received prematurely, and the associated effects will be more detrimental than for a positive time shift. However, if copies of an OFDM symbol's first samples are added to the end of the symbol transmission as a postamble, the effect of negative time shifts will be no worse than that for positive time shifts.

Bit errors in an OFDM system are generally concentrated in some severely faded subcarriers while no bit errors can be observed in the remaining subcarriers. Adaptive OFDM schemes aim to exclude those subcarriers that have a high probability for bit errors when a given symbol is being transmitted. These adaptive schemes may also vary other parameters such as the coding rate of error correction. Estimates of current channel parameters are obtained by extrapolating from measurements of previous channel performance when OFDM symbols were received. These estimates can be made at the transmitter of a duplex system, provided that the channel quality of the reverse and forward links is similar. If so, based on the predicted channel conditions, the transmitter selects the appropriate modulation for each group of subcarriers. Then the receiver has to be told which demodulation parameters to use. It is, however, a more "robust" policy to invoke explicit signalling of the receiver's required modulation mode for transmission to the transmitter on the reverse link. In adaptive OFDM systems, a lot of parameter signaling can take place and efficient and reliable signaling techniques are needed. One way to reduce signaling is to use blind detection methods, which aim to estimate the modulation method being used by the transmitter by examining the received data symbols.

Another way to improve the performance of OFDM systems is to use preequalization before transmission of each symbol. The idea is to predistort the phase and amplitude for subcarriers so that, based on the anticipated channel transfer function, the current symbol will be correctly received. Those subcarriers that will require excessive power for equalization can be blocked and the receiver can be informed as to which subcarriers were blocked.

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Combining adaptive modulation and preequalization allows fine-tuning of OFDM transmissions in fading channels. The transmitter can invest the energy not used in blocked subcarriers into the subcarriers that are actively used. The objective of this combined method is to transmit data symbols at a power level that insures a target signal-to-noise ratio (SNR) at the receiver and provides the desired bit error rate.

Keller and Hanzo compare the performance of OFDM methods that employ fixed throughput to that of methods that use time-variant-throughput. They find that uncoded fixed-throughput schemes require higher SNR's than any of the other schemes to achieve the same results. Coded fixed-throughput schemes provide consistently better results than uncoded fixed-throughput schemes. The time-variant-throughput schemes outperform comparable fixed-throughput schemes. Those time-variant schemes that are uncoded exhibit higher throughput than the coded time-variant schemes at higher SNR's. Generally, coded schemes show limited throughput at higher SNR but have better throughput at lower SNR. The authors note that the uncoded preequalized-adaptive scheme outperforms all others at higher SNR and is close in performance to the coded adaptive schemes.

—*Howard Falk*