

Information Technology: Transmission, Processing, and Storage

*Multi-Carrier
Digital
Communications
Theory and
Applications of
OFDM*

Ahmad R. S. Bahai
and
Burton R. Saltzberg

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symbol experience considerable distortion, and with longer delay spread, more samples will be affected. Using cyclic extension, the convolution changes to a circular operation. Circular convolution of two signals of length N is a sequence of length N so the inter-block interference issue is resolved.

Proper windowing of OFDM blocks, as shown later, is important to mitigate the effect of frequency offset and to control transmitted signal spectrum. However, windowing should be implemented after cyclic extension of the frame, so that the windowed frame is not cyclically extended. A solution to this problem is to extend each frame to $2N$ points at the receiver and implement a $2N$ FFT. Practically, it requires a $2N$ IFFT block at the transmitter, and $2N$ FFT at the receiver. However, by using partial FFT techniques, we can reduce the computation by calculating only the required frequency bins.

If windowing was not required, we could have simply used zero padded pre/postfix, and before the DFT at the receiver copy the beginning and end of frame as prefix and postfix. This creates the same effect of cyclic extension with the advantage of reducing transmit power and causing less ISI.

The relative length of cyclic extension depends on the ratio of the channel delay spread to the OFDM symbol duration.

2.5 Channel Estimation

Channel estimation inverts the effect of non-selective fading on each sub-carrier. Usually, OFDM systems provide pilot signals for channel estimation. In the case of time-varying channels the pilot signal should be repeated frequently. The spacing between pilot signals in time and frequency depends

on coherence time and bandwidth of the channel. We can reduce the pilot signal overhead by using a pilot signal with a maximum distance of less than the time and coherence bandwidths. Then, by using time and frequency interpolation, the impulse response and frequency response of the channel can be calculated.

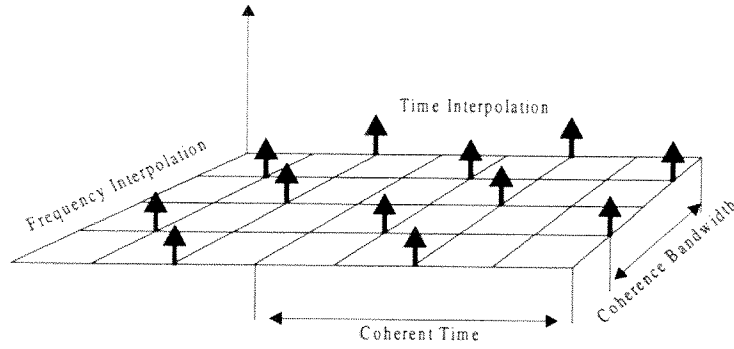


Figure 2.7. Pilot positioning in time and frequency.

Let

$$\mathbf{h}_t = (h_1, h_2, \dots, h_M)^T \quad 2.21$$

represent the overall impulse response of the channel, including transmitter and receiver filters, with length M [6]. The N -element training sequence is represented by

$$\begin{aligned} X &= [X_{ij}], \quad 1 \leq i \leq M+N-1, \quad 1 \leq j \leq M \\ X_{ij} &= \begin{cases} x_{i-j+1}, & 1 \leq i-j+1 \leq N \\ 0, & \text{elsewhere} \end{cases} \end{aligned} \quad 2.22$$

The noise samples are

$$\mathbf{n} = (n_1, n_2, \dots, n_{M+N-1})^T, \quad 2.23$$

with

$$R_n = E\{nn^*\} = LL^*, \quad 2.24$$

in which L is a lower triangular matrix, which can be calculated by the Cholesky method. The received signal is then

$$r = Xh_t + n. \quad 2.25$$

After correlation or matched filtering, the estimate of the impulse response is:

$$\hat{h}_t = X^* r = X^* X h_t + X^* n. \quad 2.26$$

If the additive noise is white, the matched filter is the best estimator in terms of maximizing signal-to-noise ratio. However, the receiver filter colors the noise. With a whitening filter the estimate is given in [5]. An unbiased estimator, which removes the effect of sidelobes, is [5]

$$\hat{h}_t = (X^* R_n^{-1} X)^{-1} X^* R_n^{-1} r = h + (X^* R_n^{-1} X)^{-1} X^* R_n^{-1} n. \quad 2.27$$

In the dual system architecture, circular convolution is replaced by multiplication. The repetition of the training sequence results in circular convolution. Therefore, Equation 2.26 is replaced by:

$$\hat{H}^\omega = X^\omega X^{\omega*} H^\omega + X^{\omega*} N^\omega, \quad 2.28$$

where superscript ω shows Fourier Transform and all products are scalar. The same procedure can be applied to Equation 2.27. This procedure is also called frequency equalization.