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Channel Estimation in OFDM: A Review

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ABSTRACT
In OFDM, the sub-carriers are orthogonal to each other. It avoids the interference between the sub-channels and hence no need of guard bands. Therefore the design of both the transmitter and receiver becomes easy, unlike conventional FDM, a separate filter is not necessary for each sub-channel. The orthogonality also allows high spectral efficiency. But OFDM requires accurate frequency synchronization between the receiver and the transmitter. This paper describes the basic introduction of OFDM system and explains the different channel estimation algorithms.

KEYWORDS: Orthogonal frequency division multiplexing, Channel Estimation

INTRODUCTION

Orthogonal frequency division multiplexing (OFDM), one of the multi-carrier techniques, features high spectral efficiency and robustness to multipath By transforming the wide-band frequency-selective channel into a set of narrow-band flat fading channels, OFDM receiver has a drastically simplified equalization process which can be accomplished using a one-tap frequency-domain equalizer. Therefore, OFDM has been employed in various commercial applications that include WLAN (IEEE 802.11a/g/n and HIPERLAN/2), WMAN (IEEE 802.16), DAB-T and DVB-T, and it is also considered a good candidate for the future 4G systems [1].In OFDM systems, the number of subcarriers is typically in the order of hundreds, or even over thousands. These subcarriers are spaced close together in the frequency domain, and are supposed to be orthogonal to each other. As such, the synchronization requirement (which includes timing and carrier frequency synchronization) for OFDM systems is more stringent than that for single carrier systems [1].In OFDM systems, carrier frequency synchronization is usually done in two steps. The first step is coarse synchronization, which usually reduces the CFO to within one-half of the subcarrier spacing [1]; this is followed by fine carrier synchronization, which further estimates and reduces the residual CFO.The performance of the system depends generally on modulation schemes, channel estimation techniques used to estimate channel. The capacity of communication system increases linearly with the number of antennas, when perfect knowledge about the channel is available at the receiver. In practice, the channel estimation procedure is done by transmitting pilot (training) symbols that are known at the receiver. Further, channel estimation depends on the pattern of transmitting pilots [2].OFDM technique converts a frequency selective channel into a number of frequency nonselective channels by dividing the available spectrum into a number of overlapping and orthogonal narrowband sub channels where each of them sends own data using a subcarrier. A block diagram of OFDM systems is shown in figure (1).

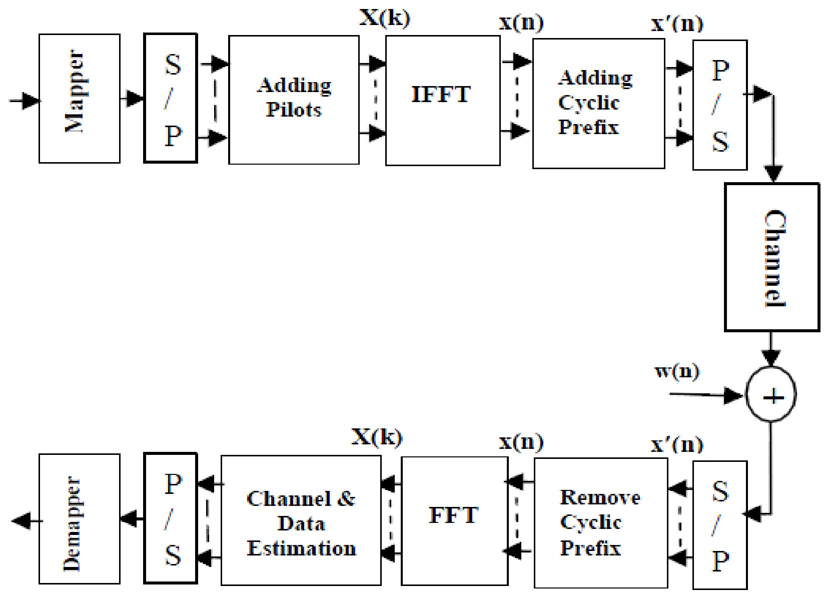


Figure 1: The OFDM System in baseband model[4]

At first, in transmitter the binary inputs are grouped to get an M-ary symbol. According to a predefined baseband modulation such as QPSK and MQAM, the obtained symbols are modulated using a signal mapper subsystem. In the next step, an S/P sub-block converts the serial input symbols to a block data which can be considered as a vector X=[X_0, X_1 …, X_{N-1}]. The vector size is 'N' which determine the number of subcarriers in OFDM signal. Any subcarriers will be modulated by the obtained symbols in data vector using IFFT technique and consequently, the time domain of the OFDM signal are calculated which can be written as equation (1).

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{LN-1} X_k e^{j\frac{2\pi}{LN}kn} \quad 0 \le n \le LN-1 \text{ ……………………………………………………..(1)}$$

Where 'L' is an oversampled factor which can be set to any number as: 2, 4, 8,16 [4].

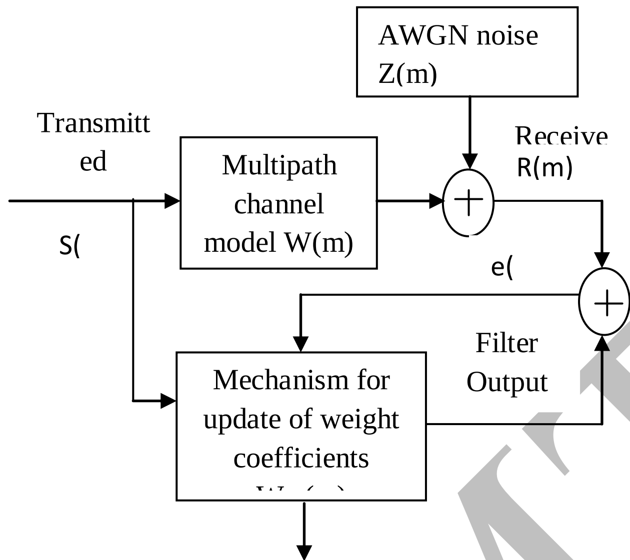
OFDM CHARACTERISTICS

The OFDM systems have the following distinctive characteristics if compared to conventional OFDM systems [3]:

1) Different channel responses and channel energies across different bands,
2) Different carrier frequency offsets across different bands,
3) The use of zero padding (ZP) instead of cyclic prefix (CP),
4) The interplay between the timing and the frequency hopping.

CHANNEL ESTIMATION

In any communication systems, channel estimation is a most important and challenging problem, especially in wireless communication systems. Usually, the transmitted signal can be degraded by many detrimental effects such as mobility of transmitter or receiver, scattering due to environmental objects, multipath and so on. These effects cause the signal to be spread in any transformed domains as time, frequency and space. To reducing these effects anyone must estimate the channel impulse response (CIR). Channel estimation has a long history in single carrier communication systems. In these systems, CIR is modeled as an unknown FIR filter whose coefficients are time varying and need to be estimated. There are many /channel estimation methods that can be used in multicarrier communication systems but the especial properties of multicarrier transmission systems give an additional perspective which forces to developing new techniques to channel estimation in wireless communication systems. In general, channel estimation methods based on OFDM systems can be categorized into two groups as blind and non-blind techniques. In the former, all of the techniques use the statistical behavior of the received signals and therefore, to obtain the accurate CIR a large amount data is required [4]. Finally, the complexity of computations is very high. In the later, to obta



a good estimation of channel, the transmitter sends a collection of data aided as pilots whose are previously known by the receiver. Often, most OFDM based systems as IEEE 802.11a and hyperLAN2 use pilots in frequency domain in order to sampling the faded channel in frequency domain. Channel estimation based on pilot arrangement which have been used in many application systems especially wireless communication and power line communication channels can be divided in two main categories as block type and comb type [4].

TECHNIQUES OF CHANNEL ESTIMATION

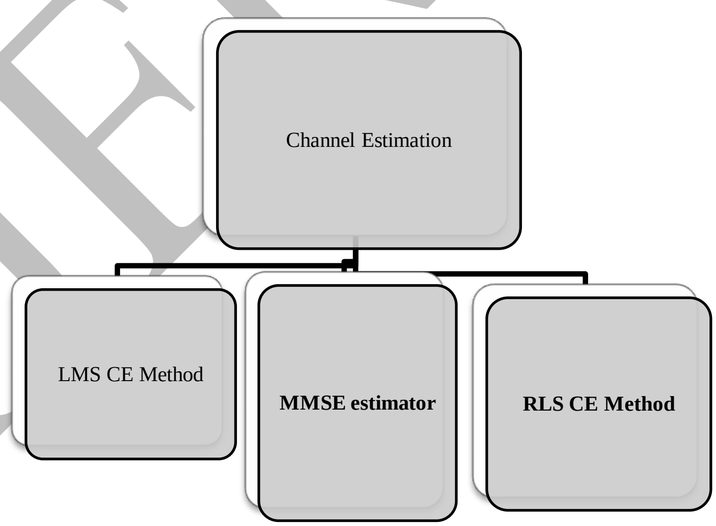


Figure2: Techniques of Channel estimation

LMS CE Method

An adaptive algorithm is a process that changes its parameters as it gain more information of its possibly changing environment. Among numerous iterative techniques that exist in the open literature, the popular category of approaches which are obtain from the minimization of the MSE between the output of the filter and desired signal to perform CE as shown in Figure2 [5].Figure 3: Scheme for adaptive CE.[5]

The signal S(m) is transmitted via a time-varying channel W(m), and corrupted by an additive noise estimated by using any kind of CE method. The main aim of most channel estimation algorithms is to minimize the mean squared error (MMSE) i.e., between the received signal and its estimate.

RLS CE Method

The RLS CE requires all the past samples of the input and the desired output is available at each iteration. The objective function of a RLS CE algorithm is defined as an exponential weighted sum of errors squares:

$$c(m) = \sum_{m=1}^{n} \lambda^{n-m} e^{H}(m)e(m) + \delta\lambda^{n} W^{H}(m)W(m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where δ is a positive real number called regularization parameter, e(m) is the prior estimation error, and λ is the exponential forgetting factor with $0 < \lambda < 1$. The prior estimation error is the difference between the desired response and estimation signal:

$$e(m) = H(m) - W^{H}(m)S(m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The objective function is minimized by taking the partial derivatives with respect to W(n) and setting the results equal to zero.

$$\frac{\delta C(m)}{\delta W(m)} = 0 = -2\sum_{m=1}^{n} \lambda^{n-m} S(m)e^{H}(m) + 2\delta\lambda^{n}W(m) = -2\sum_{m=1}^{n} \lambda^{n-m} S(m)[H(m) - W^{H}(m)S(m)]^{H} + 2\delta\lambda^{n}W(m)$$

$$W(m)\left[\sum_{m=1}^{n} \lambda^{n-m} S(m)S^{H}(m) + \delta\lambda^{n} I\right] = \sum_{m=1}^{n} \lambda^{n-m} S(m)H^{H}(m)$$

$$R_{S}(m)W(m) = R_{Sh}(m)$$

$$W(m) = R_{S}^{-1}(m)R_{Sh}(m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where $R_s(m)$ is the transmitted auto-correlation matrix $R_s(m) = \sum_{m=1}^{n} S(m)S^{H}(m) + \delta\lambda^{n} = \lambda R_s(m-$ 1+SmSH(m) and Rsh(m) is the cross correlation matrix i.e.,

$$R_{sh}(m) = \sum_{m=1}^{n} \lambda^{n-m} S(m)H^{H}(m) = \lambda R_{sh}(m-1) + S(m)H^{H}(m)$$

According to the Woodbury identity, the above $R_{sh}(m)$ can be written as:

$$R_{sh}^{-1}(m) = \lambda^{-1}R_{sh}^{-1}(m-1) - \frac{\lambda^{-2}R_{sh}^{-1}(m-1)S(m)S^{H}R_{sh}^{-1}(m-1)}{1+\lambda^{-1}S^{H}(m)R_{sh}^{-1}(m-1)S(m)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

For convenience of computing, let $D(m) = R_{sh}(m)$ and

$$K(m) = \frac{\lambda^{-1}D(m-1)S(m)}{1+\lambda^{-1}S^{H}(m)D(m-1)S(m)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The K(m) is referred as a gain matrix. We may rewrite (2) as:

$$D(m) = \lambda^{-1}D(m-1) - \lambda^{-1}K(m)S^{H}(m)D(m-1) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

So simply (13) to

$$K(m) = D(m)S(m) = R_{sh}^{-1}(m)S(m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Substituting (7), (8) into (4), we obtain the following RLS CE formula:

$$W(m) = W(m-1) + K(m)[H(m) - W^{H}(m-1)s(m)]^{H} = W(m-1) + K(m)\varepsilon^{H}(m) \quad \ldots\ldots\ldots\ldots (9)$$

Where ε(m) is a prior estimation error as

$$\varepsilon(m) = H(m) - W^{H}(m-1)S(m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Therefore, equation (10) is the recursive RLS CE algorithm to update channel coefficient.

MMSE estimator [6]

The Minimum Mean Square Error (MMSE) estimator is given by

$$\widehat{h_{64}} = FR_{hy}R_{yy}^{-1}y_{64,T12} \quad \ldots \quad (11)$$

Where

$$R_{hy} = E\{h_t(t)y_t^H\} = R_{hh}F^HX^H \quad \ldots \quad (12)$$

$$R_{yy} = E\{y_ty_t^H\} = XFR_{hh}F^HX^H + \sigma_w^2 I_{64} \quad \ldots \quad (13)$$

are the cross covariance matrix between ${h_t}^{(t)}$and y_t and the auto-covariance matrix of y_t. R_{hh} is the auto-covariance matrix of $h_t(t)$, σ^2w is the noise variance $E\{|w_t|^2\}$and $\mathbf{I_{64}}$ is the identity matrix of size 64. To be able to implement the MMSE estimator the noise variance, σ^2w, and the channel auto-covariance matrix, R_{hh} ,need to be estimated.

CONCLUSION

Orthogonal frequency-division multiplexing (OFDM) is a type of frequency-division multiplexing (FDM) method which can be used as a digital multi-carrier modulation technique. Usual-ly a large number of closely-spaced orthogonal sub-carriers are used to carry data. The data is splited into various parallel data streams or channels, one for each sub-carrier. In this paper, the basic concepts of Orthogonal Frequency Division Multiplexing (OFDM) systems are discussed. The various channel estimation techniques are described for further research.

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