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Channel Estimation of Orthogonal Frequency Division Multiplexing (OFDM) System

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Abstract

Orthogonal frequency division multiplexing (OFDM) provides an effective and low complexity means of eliminating inter symbol interference for transmission over frequency selective fading channels. This technique has received a lot of interest in mobile communication research as the radio channel is usually frequency selective and time variant. In OFDM system modulation may be coherent or differential Channel state information (CSI) is required for the OFDM receiver to perform coherent detection or diversity combining if multiple transmit and receive antennas are deployed. In practice CSI can be reliably estimated at the receiver by transmitting pilots along with data symbols. Pilot symbol assisted channel estimation is especially attractive for wireless links where the channel is time-varying. In this research work, we investigate and compare various efficient pilot based channel estimation schemes for OFDM systems.

Keywords: *OFDM, Channel estimation, Channel State information, Pilot based channel estimation and Rayleigh fading.*

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I. INTRODUCTION

Wireless systems are expected to require high data rates with low delay and low bit-error-rate (BER).In such situations, the performance of wireless communication systems is mainly governed by the wireless channel environment. In addition, high data rate transmission and high mobility of transmitters and/or receivers usually result in frequency-selective and time selective, fading channels for future mobile broadband wireless systems. Moreover perfect channel state information (CSI) is not available at the receiver. Thus in practice, accurate estimate of the CSI has a major impact on the whole system performance.

It is also because, in contrast to the typically static and predictable characteristics of a wired channel, the wireless channel is rather dynamic and unpredictable, which makes an exact analysis of the wireless communication system often difficult. For a typical wireless system, RF signal transmission between two antennas commonly suffers from power loss, which affects its performance. This power loss between transmitter and receiver is a result of three different phenomena

1) Distance-dependent decrease of the power density called path loss or free space attenuation

2) Absorption due to the molecules in the atmosphere and 3) Signal fading caused by terrain and weather conditions in the propagation path.

Fading channel models are often used to model electromagnetic transmission of information over wireless media such as cellular phone and broadcast communication. The shadow fading occurs when terminals move through areas with obstacles of various sizes, such as mountains, buildings and tunnels. Occasionally, these obstacles will shadow or completely cut off the signal. Although the consequences of such shadowing effects will depend on the size of an obstacle and on the distance to it, the received signal strength will inevitably vary.

The effect of shadow fading can be decreased with some awareness in network planning. For example, by placing base stations as high as possible or close to each other it is possible to avoid some obstacles in transmission. However, it is not only the shadow fading that is the most

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unpredictable power loss. Multi-path fading, Rayleigh fading or short term fading are another types of fading, involving irregular signal strength variations and are usually problematic to overcome. Rayleigh fading is a result of a reception of several signals at the receiver incoming and reflected from many different objects and directions in the area. Due to their different traveling distances, the signals are usually not in phase, reinforcing or extinguishing each other.

The movement of the terminal causes continuous and unpredictable variations of the signal phases over time, making the attenuation vary variable and extremely high at some points (fading dips). Rayleigh fading is most perceptible in urban areas. Dips will occur more frequently at higher frequencies and more rapid mobile movement. To avoid dips it is necessary to attain a sufficient fading margin. The average value of the signal must be at least as many decibels above the receiver sensitivity level as the strongest expected dip. To overcome these problems special reception techniques are normally used, namely the multiple receiver combining techniques known as diversity.

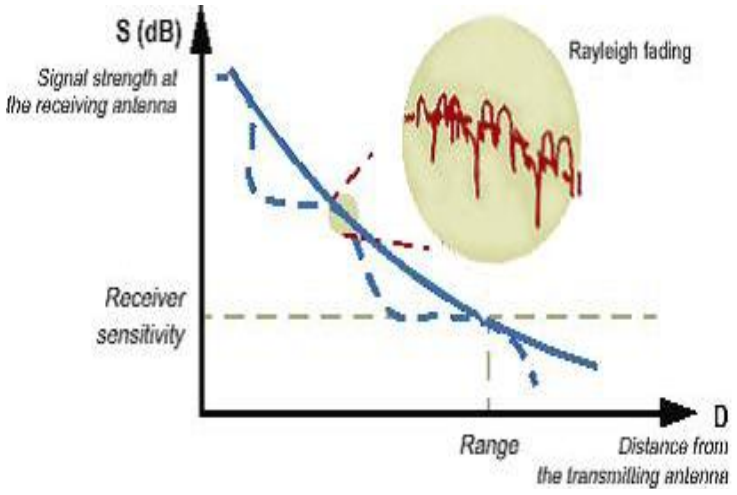


Figure1: Rayleigh fading

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The fading phenomenon can be broadly classified into two different types: 1) large-scale fading and 2) small-scale fading.Large-scale fading occurs as the mobile moves through a large distance, for example, a distance of the order of cell size. It is caused by path loss of signal as a function of distance and shadowing by large objects such as buildings, intervening terrains, and vegetation. Shadowing is a slow fading process characterized by variation of median path loss between the transmitter and receiver in fixed locations. On the other hand, small-scale fading refers to rapid variation of signal levels due to the constructive and destructive interference of multiple signal paths (multi-paths) when the mobile station moves short distances.

This Research work focuses on investigating the effect of fading in modern digital communication techniques such as orthogonal frequency division multiplexing. OFDM has been widely applied in wireless communication systems. For conventional coherent detection, accurate CSI is needed for the receiver processing. Although channel estimation can be avoided by using differential modulation techniques, these techniques will fail catastrophically in the fast fading channel, where the channel impulse response (CIR) varies significantly within the symbol duration.

II.OFDM SYSTEM

The key elements of OFDM systems are described below.

A. Orthogonality

In OFDM systems, the two periodic signals are orthogonal when the integral of their product over a period is equal to zero. This can be represented in continuous time as

$$\int_0^t \cos(2\pi f_0 nt)\cos(2\pi f_0 mt)dt = 0 \quad (1)$$

For the case of discrete time, it can be represented as

$$\sum_{k=0}^{N-1} \cos\left(\frac{2\pi kn}{N}\right)\cos\left(\frac{2\pi km}{N}\right)dt = 0 \quad (2)$$

Where, m≠n in both cases.

B. Subcarriers in OFDM systems

Each Subcarrier in an OFDM system is a sinusoidal with a frequency that is an integer multiple of fundamental frequency. Each subcarrier can be expressed as a Fourier series component of the composite

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signal. The subcarriers waveform can be mathematically expressed as

$$s(t)=\cos(2\pi f_c t+\theta_k)=a_n\cos(2\pi n f_0 t)+b_n\sin(2\pi n f_0 t) \quad (3)$$

Where,

$\varphi_n = \tan^{-1}(b_n / a_n)$.

The Sum of these Subcarriers is then referred to baseband OFDM signal as

$$s_b(t)=\sum_{n=0}^{N-1}\{a_n\cos(2\pi n f_0 t)-b_n\sin(2\pi n f_0 t)\} \quad (4)$$

C. Inter Symbol Interference (ISI)

Inter Symbol Interference (ISI) is a form of distortion of a signal in which one symbol interferes with subsequent symbols. This is an unwanted phenomenon as the previous symbols have similar effect as noise; thus, making the communication less reliable. ISI is usually caused by multipath propagation or the inherent non–linear frequency response of a channel causing successive symbols to "blur" together.

The presence of ISI in the system introduces error in decision device at the receiver output. Therefore, in the design of transmitting and receiving filters, the objective is to minimize the effects of ISI and thereby, deliver the digital data to its destination with the smallest error rate possible.

D. Inter-carrier Interference (ICI)

Presence of Doppler shifts and frequency and phase offsets in an OFDM system causes loss in orthogonality of the subcarriers. As a result, interference is observed between subcarriers. This phenomenon is known as inter-carrier interference (ICI).

E. Cyclic Prefix

The Cyclic Prefix (CP) or Guard Interval is a periodic extension of the last part of an OFDM symbol that is added to the front of symbol in a transmitter, and is removed at the receiver before demodulation. Cyclic prefix acts as a guard interval. It eliminates the inter-symbol interference from the previous symbol. It acts as a repetition of the end of the symbol, thus allowing the linear convolution of a frequency–selective multipath channel to be modeled as circular convolution which in turn may be transformed to the frequency domain using a discrete Fourier transform.

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This approach allows for simple frequency–domain processing such as channel estimation and equalization.

F. Modulation

In an OFDM system, the high data rate information is divided into small packets of data which are placed orthogonal to each other. This is achieved by modulating the data by a modulation technique such as QPSK and QAM. After this, IFFT is performed on the modulated signal which is further processed by passing through a parallel to serial converter. In order to avoid ISI, a cyclic prefix is added to the signal as discussed above.

G. Demodulation

In this case, the received data is first passed through a low pass filter to remove the cyclic prefix. After this, FFT is performed and the serial data obtained is converted into the parallel signal. A demodulator is used to get back the original signal.

III. DISCRETE TIME BASED OFDM SYSTEM

The block diagram of discrete-time baseband OFDM system is depicted in Figure 3. In Figure 3, an OFDM signal consists of N subcarriers that are modulated by N complex symbols selected from a particular QAM constellation. These baseband modulated symbols are then passed through serial to parallel converter which generates complex vector of size N. This complex vector of size N can be expressed as

$$X=[X_1,X_2,X_3,X_4.....X_{N-1}] \quad (5)$$

X is then passed through the IFFT block to give

$$x=WX \quad (6)$$

Where, W is the N × N IFFT matrix. Thus, the complex baseband OFDM signal with subcarriers into time domain samples can be written as

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{\frac{j2\pi kn}{N}} \quad n = 0, 1, \ldots, N-1. \quad (7)$$

After parallel-to-serial conversion, a cyclic prefix with a length of Ng samples is appended before the IFFT output to form the time-domain OFDM symbol,

$$S = [S_{0,}.....,S_{N+Ng-1}] \quad (8)$$

Where, $Si = X_{(i-Ng)N}$ and $()_N \triangleq imodN.$

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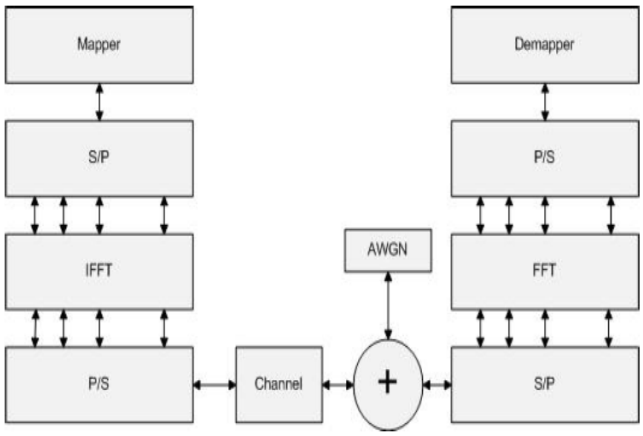


Figure3: A Discrete Time baseband OFDM system

The useful part of OFDM symbol does not include the *Ng* prefix samples and has duration of *Tu* seconds. The samples (*s*) are then amplified, with the amplifier characteristics is given by function *F*. The output of amplifier produces a set of samples given by

$$Y = [Y0, Y1, \ldots\ldots, Y_{N+Ng-1}] \quad (9)$$

This signal is then serially transmitted through a multipath radio propagation channel which is subject to additive white Gaussian noise (AWGN) with variance $\sigma 2 = N0/2$, where $N0$ is power spectral density. At the receiver front end, the received signal is applied to a matched filter and then sampled at a rate Ts = Tu/N. After dropping the CP samples (Ng), the received sequence *z*, assuming an Additive white Gaussiannoise channel, can be expressed as

$$z = F(Wd) + \eta \quad (10)$$

Where, the noise vector η consists of *N* independent and normally distributed complex random variables with zero mean and variance $\sigma n2=E\{|\eta n|2\}$. Subsequently, the sequence *z* is fed to the fast Fourier transform (FFT), which produces the frequency-domain sequence *r* as

$$r = W^H z \quad (11)$$

Where, *k*th element of *r* is given by

$$r_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} z_n e^{\frac{-j2\pi kn}{N}} \quad k=0, 1, 2,\ldots, N\text{-}1 \quad (12)$$

Finally, the estimated symbols vector *d* can be obtained from r. It is to be noted that the demodulation is performed based on the

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assumption of perfect symbol timing, carrier frequency, and phase synchronization. It is also to be noted that due to the use of CP, the inter-block interference between contiguous OFDM blocks in frequency domain is eliminated so each OFDM block can be processed independently, provided that the length of CP is equal to or larger than the delay spread of the channel. The main drawbacks of OFDM systems are high peak-to-average-power ratio (PAPR), bit error rate (BER) and high sensitivity to carrier frequency offset (CFO). Moreover, OFDM does not obtain frequency diversity. If a deep fade occurs close to the frequency of a subcarrier, reliable data detection carried by these faded subcarriers becomes difficult.

IV.COMMUNICATION SYSTEM

Wireless signals usually subject to fading and dispersion. This offers implications for the design of wireless communication systems. In such cases, a transmitted signal will be composed of a sequence of shift-orthogonal and overlapping pulses, distorted by the channel. OFDM systems usually experience frequency selectivity in a channel, so the same require equalization in the receiver. The term equalization means the removal of distortion or the de-convolution of channel response from the received signal. Mathematically, a communication system can be described in terms of the complex baseband transmitted signal as

$$s(t) = \sum_{l\epsilon Z} a_l \, \delta(t - lT) \qquad (13)$$

A pulse shaping filter is also usually introduced, which makes the above equation as

$$s_T(t) = \sum_{l\epsilon Z} a_l \, c_T(t - lT) \qquad (14)$$

Where Z is the set of integers, a_l is an element from the complex symbol sequence, $c_T(t)$ is the transmitter pulse shape and T is the symbol spacing. The bandwidth of this transmitted pulse $c_T(t)$ shape is denoted by W. Any digital modulation techniques such as PAM, PSK or QAM can be used in OFDM systems; however in this work, QAM is considered as modulation technique. The channel state information is usually expressed mathematically in terms of the channel impulse response (CIR) which is a function of time and delay. It is denoted as h(t,).This impulse response incorporates both fading, time selective effects and dispersive, frequency selective

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effects. To determine the CIR at a given time (say t), the channel has the impulse response described as a function of delay (ξ). In OFDM systems, the receiver usually have a fixed front-end filter with impulse response $C_R(t)$.The impulse response of the overall pulse shape is given by

$$c(t) = c_T(t) \otimes c_R(t)$$

(15)

The overall CIR in terms of pulse shape is defined as

$$u(t,\xi) = c(\xi) \otimes h(t,\xi)$$

(16)

Where, $\otimes$ denotes convolution. The overall CIR with $\xi = t - lT$ and the convolution explicitly shown is expressed as

$$u(t, t-lT) = \int_{-\infty}^{\infty} c(t-lT-\tau)\, h(t,\tau) d\tau$$

(17)

At the output of the front-end filter, the received signal is given by

$$s_R(t) = \sum_{l \epsilon Z} a_l\, u(t, t-lT) + \eta(t)$$

(18)

Where, (t) is the filtered output due to additive white Gaussian noise (AWGN) with two-sided power spectral density (PSD) $N0/2$.

V. CHANNEL ESTIMATION TECHNIQUES

In wireless communication, the channel is usually unknown a priori to the receiver. Therefore to do the channel estimation, a pilot symbol aided modulation is used, where known pilot signals are periodically sent during the transmission. In general, the performance of channel estimation depends on the number, the location, and the power of pilot symbols inserted into OFDM blocks. To mathematically analyze this, consider a fading multipath channel with the multipath delay spread τmax and the maximum Doppler frequency(f_d). To recover the channel state information (CSI), the spaces between pilot symbols in the time and frequency domain must satisfy two-dimensional (2-D) sampling theorem, ie,

$f_d\, T\, d_t \leq ½$(19)

$$\tau_{max}\, \Delta f\, d_f \leq 1 \qquad (20)$$

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Where T is the OFDM block duration, Δf is the subcarrier spacing; $d_t$and d_f are the numbers of samples between pilot symbols in the time domain and frequency domain, respectively.

A. Channel estimation in slow fading channels.

In slow fading channels, the channel slowly changes over a number of OFDM symbol blocks. In such channels, channel estimation is based on pilot symbols, which are inserted into all subcarriers of OFDM symbol blocks within a specific period. These pilot symbols are usually called training symbols and a batch of OFDM symbols follows the training symbols. For channel estimation based on training symbols, the first step is to estimate CSI corresponding to training symbols.

Using this information, the CSI corresponding to subsequent data symbols can be tracked and further improved by decision directed channel estimation. If the channel varies slowly over OFDM blocks, the estimated CSI based on previous training symbols are generally reliable so such estimated channel state may be used in data detection. However in situations, the channel varies fast over time, the training symbols will be sent more frequently to get reliable channel estimates, and thus, the overall system efficiency is reduced.

B.Channel estimation in fast fading channels

In fast fading channels, the channel varies significantly over one OFDM symbol block. In such cases, the orthogonality among the OFDM subcarriers is usually lost and the ICI is created. The severity of ICI depends on the normalized Doppler frequency (f_dT). In the presence of ICI, the amount of channel states that need to be estimated for reliable data detection increases. Not only the individual subcarrier frequency responses but also the interference among subcarriers in each OFDM symbol are to be estimated.

In such a case, an underdetermined system occurs if standard channel modelling is employed, as the number of unknowns are more than the number of measurements (pilot symbols). In order to reduce the number of unknown channel parameters, simplification approaches are exploited for channel estimation.

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VI.CHANNEL ESTIMATION OF OFDM SYSTEM

For an OFDM mobile communication system, the channel transfer function at different subcarriers appears unequal in both frequency and time domains. Therefore, a dynamic estimation of the channel is always required. Pilot-based approaches are widely used to estimate the channel properties and correct the received signal.

A. Block type pilot arrangement

In this scheme, 16-QAM modulation scheme is used for a 64-subcarrier OFDM system, with a two ray multipath channel. The channel impulse response h(t) is a time limited pulse train in the form of

$$h(t) = \sum_m \alpha_m \delta(t - \tau_m T_s) \quad (21)$$

B. Comb type pilot arrangement

In comb type pilot arrangement, Rayleigh-fading channel is considered, with channel impulse response

$h(L)=[h(0),\ldots\ldots\ldots,h(L-1)]^T$

Here, L=40 is the number of taps and are uncorrelated complex Gaussian random variables with zero mean.

VII. RESULT & DISCUSION

For comb type pilot arrangement, an OFDM system with N=1024 subcarriers is considered. The frequency selective Rayleigh channel has L=40 zero-mean uncorrelated complex Gaussian random taps. The spacing between pilots are taken as 4. So the number of pilots are 256 and number of information symbols are 768. In the simulation, PSK modulation is considered.

Symbol Error Rate (SER) performance (SNR versus SER) for different modulations in MMSE and LSE estimators respectively. It shows that as SNR increases the symbol error rate decreases, as theoretically expected. The FFT, spline, linear and cubic interpolation techniques are applied using the LSE estimation. It is found that spline interpolation having better performance than linear and other interpolation techniques.

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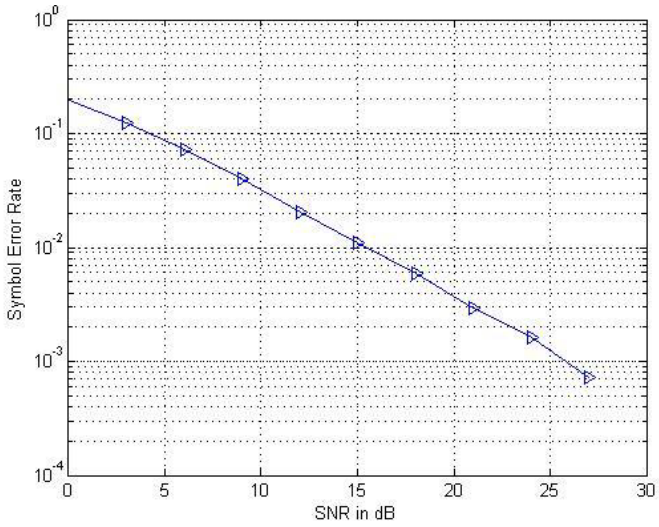


Figure4: SER for MPSK Modulation

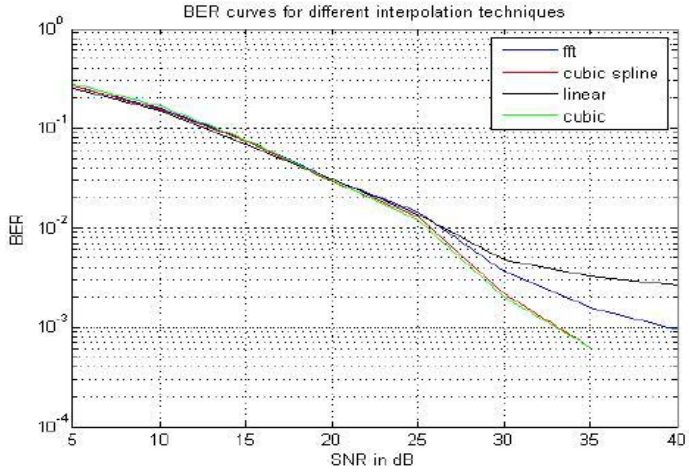


Figure5: BER Curves for Different FFT

CONCLUSION

Comb type pilot arrangement is suitable to use for fast fading channel where the channel impulse response is changing very fast, even if one OFDM block is present. So, comb type of pilot arrangement is not suitable in this case. Both data and pilot carriers in one block of OFDM symbols are used. Pilot carriers are used to estimate the channel impulse response. The estimated channel can be used to get back the data sent by transmitter certainly with some error. In the simulation, 1024 number of carriers in one OFDM block is used, in

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which one fourth are used for pilot carriers and rest are of data carriers. BER for different SNR conditions for M-PSK signaling is calculated.Various interpolation techniques for channel estimation are also used. It is found that higher order interpolation technique (spline) is giving better performance than lower order interpolation technique (linear).

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