AN EFFICIENT DFT BASED CHANNEL ESTIMATION FOR OFDM SYSTEMS THAT MAINTAINS COMPLEXITY-PERFORMANCE TRADE-OFFS AND WITH LEAKAGE SUPPRESSION

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Abstract
Although tremendous progress has been made on the past years on channel estimation in OFDM systems still it is considered as area of concern in wireless communication. A novel channel estimation technique with virtual subcarriers is proposed in this work namely DFT Based Channel Estimation for OFDM Systems that maintains Complexity-Performance Trade-Offs and with leakage suppression using virtual subcarriers. The flow of the proposed approach is initially starts with time domain (TD) index set estimation considering the leakage effect then followed by low-complexity TD post-processing to suppress the leakage. The proposed channel estimator approach outperforms the existing channel estimators in terms of efficiency and performance. Finally the performance and complexity of the proposed algorithm are analyzed by simulation results.

KEYWORDS: OFDM, Channel estimation, Time domain, Wireless communications

I. INTRODUCTION
Wireless communications are broadly classified into three different categories namely i) Conventional communication systems such as FDMA, TDMA which mainly has two drawbacks one is low data rate and low spectral efficiency. ii) Existing communication systems like CDMA are suitable for mobile and radar communication but the main drawback is data rate (speed). iii) Future generation communication models such as OFDM are used in Applications like 3G, 4G, LTE, WIFI, and WIMAX. Orthogonal frequency division multiplexing is considered as highly successful communication model compares to conventional communication models because of low sensitivity to multipath propagation and eminent spectral efficiency. Orthogonal frequency division multiplexing too suffers from some drawbacks, high peak to average power ratio is main drawback which occurs due to the insufficiency power distribution by high power amplifier which results in in-band and out-band distortion. Digital communication are comprised of two communication representations pass band representation and base band representation, pass band represents continuous mode of communication while base band represents digital mode of communication. In our proposed work we present the base band representation of orthogonal frequency division multiplexing signal with N sub carriers as follows

\[ x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi k N_t s} t, \quad 0 \leq t \leq N_t s \]  (2.1)

N represents number of sub carriers
\( t_s \)=Sampling time
X represents the frequency domain of orthogonal frequency division multiplexing symbols such as \( X=[X_1, X_2 \ldots \ldots X_{N-1}] \)
T=Nts = symbol duration. When the number of sub carriers is large then it can be treated as complex Gaussian process by the central limit theorem, this complex Gaussian process technically called as Peak to average power ratio. In order to resolve this issue several theories are proposed in the literature. One of such theory proposed in the literature is \( \mu \)-law Companding; it reduces the Peak to average power ratio impact on orthogonal frequency division multiplexing in small amount. To overcome the drawback of \( \mu \)-law Companding in our proposed work we present the Non linear Companding transform technique for efficient results, acceptable to all types of scenarios like SISO, MIMO, MISO AND SIMO, no inter carrier interference and on the other hand it has so many drawbacks namely delay, distortion and finally peak to average power ratio.

II. COMMUNICATIONS AND OFDM

As technology transforming it’s appearance along with the generation and time respectively, then according to that Communication is also evolving it’s way in secured and faster day by day to give more comforts to the mankind and now the communication has touch it’s new level where once upon a time the planet earth is termed as ‘Concrete jungle’ by many people and now due to the high advanced technological developments in the aspects of communications now the planet earth is called as ‘Transforming world’. In olden communication means a way of approach to communicate with people with near and far end people. As in olden days Travelling on animals is only source to communicate with the dear ones on the longer distances. As Kingdoms starts to expand to show superiority slowly new places came to existence which is already their but has to be discovered like USA etc.

Then water travelling too starts using to communicate with people on longer distance but it takes too long time. Then the beginning of the industrialization starts which creates drastic changes in making way of living and way of thinking. It shows its impact in such a way that the development from 1000 A.D. to 1600 A.D. is considered as one era and the development from 1600 A.D. to 2000 A.D. is considered as one era. The industrial era mainly concentrates to provide more and more comfort to mankind by decreasing strength and increasing productivity. This industrialization era starts showing its impact on communications domain. This revolution in the communication domain starts with the invention of telephone by the graham bell which creates the way for the new ideas in the future generation for better communication techniques. The communication techniques have been broadly classified into two categories namely wireless and wire communications respectively. At the time of world war to show the superiority over each other the axle and axis powers starts inventing new way of communications although it starts for bad cause but at the end it has done good for mankind and the wireless communications came into existence. At the starting the wireless communications have been used for high level military communication purposes and some high equipped purposes. After some years it came to public service by the USA at first. Later on spectrum starts playing crucial role as all know the communication which we are making through the mobile and internet are possible because of the microwaves which are next to the radio waves which are termed as long distance communication waves.

Communications are classified into three different sections based on the different aspects as discussed below. After comparing with traditional communication techniques namely FDMA, TDMA, CDMA orthogonal frequency division multiplexing (OFDM) communication system has great spectral efficiency and high data rate.

(i) Conventional communications techniques

(a) FDMA
Orthogonal Frequency Division Multiplexing (OFDM) System

Orthogonal frequency division multiplexing (OFDM) communication system has number of advantages over conventional communication techniques namely FDMA, TDMA and CDMA. Orthogonal frequency division multiplexing (OFDM) communication system has better spectral efficiency, high data rate, low inter carrier interference and moreover it is termed as future generation communication system because of its flexible and reliable high speed data rates, high spectral efficiency, high quality service and robustness against narrow band interference and frequency selective Fading. Orthogonal frequency division multiplexing (OFDM) communication technique has many advantages compares to the conventional communication techniques as follows (i) High spectral efficiency (ii) Immunity to the effects of fading.

In an OFDM systems the channel estimation plays an important role where there are many methods namely Least minimum mean square error, DFT based estimators. Though the initial method has better performance but suffers from complexity.

The method which we propose now for OFDM Systems that maintains Complexity-Performance Trade-Offs and with leakage suppression using virtual subcarriers also achieving better performance.

III. GENERALIZED FRAMEWORK FOR OFDM CHANNEL ESTIMATION

Consider an OFDM system with N subcarriers in which U subcarriers with index set $\Omega_U$ are actually used, i.e., $\Omega_U \subset \Omega_N = \{0, 1, \ldots, N - 1\}$. Among $\Omega_U$, P subcarriers with index set $\Omega_P \subset \Omega_U$ are used for pilot subcarriers. Here, $V = (N - U)P/U$ subcarriers with index set $\Omega_V \subset \Omega_N \setminus \Omega_U$ can be considered as artificial pilot subcarriers.

Also, a length-G cyclic prefix (CP) with index set $\Omega_G = \{0, 1, \ldots, G - 1\}$ is used, it is assumed that G is larger than the maximum delay spread $\tau_{\text{max}}$, which is much larger than the maximum number of paths, L, i.e., $L \ll \tau_{\text{max}} \ll G$. Also, P and $\Omega_P$ are assumed to be well designed for successful channel estimation.

Let $\Omega_T$ be the index set of the nonzero CIR taps. Then, the $G \times 1$ CIR vector $h$ can be written as

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

with $G \times G$ covariance matrix $R = \text{E}\{hh^H\}$, where $h(n)$ is the complex gain at the nth tap and nonzero only when $n \in \Omega_T$. Then, after the CP removal, the received vector in the TD can be written as

$$y = x \bigotimes h + n \quad (1)$$

where $x$ is the $N \times 1$ transmitted OFDM symbol vector in the TD before the CP insertion, n is the $N \times 1$ independent identically distributed (i.i.d) complex white Gaussian noise vector in the TD with mean zero and covariance matrix $\sigma_n^2 I_N$ and $\bigotimes$ denotes the circular convolution.

Here, the time and frequency synchronizations are assumed to be perfect by applying good synchronization schemes. Let $\Omega_F$ and $\Omega_T$ respectively be the selected FD and TD index sets of the DFT-based channel estimator. Also, F denotes the $N \times N$ unitary DFT matrix with $F_{m,n} = \exp(-\frac{\pi j mn}{N})$. Then, the estimated CIR $\hat{h}$ and channel frequency response $\hat{g}$ can be respectively

$$\hat{g} = F_{U,T} \hat{h} = \frac{1}{N_P} \Phi(F_{P,T} h + Q_{F_{P,T} h}) \quad (2)$$

$$\hat{h} = \frac{1}{N_P} \Phi(F_{P,T} K Q_{F_{P,T} h} y) \quad (3)$$

where K and P respectively denote the $|\Omega_T| \times P$ FD post processing matrix and the $|\Omega_T| \times |\Omega_T|$ TD post-
processing matrix, \( Q \triangleq \text{diag}^{-1}(F_{P,Nx}) \), and \( \Phi \triangleq F_{U,T}P(F_{P,T})^H \). In this letter, a slowly time-varying channel is assumed so that \( K \) and \( P \) need to be computed once in a long period and \( Q \) can be pre-computed so that the corresponding complexity is negligible. Thus, computing (2) and (3) requires \( N^3 \log_2 N \) complex multiplications for the \( N \)-point fast Fourier transform (FFT) operation \([5]\) (\( F_{P,NY} \)), \( P \) for the LS estimation (\( Q_{F_{P,NY}} \)), \( (K) \) for the FD post-processing matrix multiplication complexity (the number of complex multiplications) of a generalized DFT-based channel estimator can be expressed as

\[
C = \frac{2N}{\alpha} \log_2 \frac{N}{\alpha} + N + \frac{N + 1}{3} \log_2 (N + 1) + (K) + (P) \tag{4}
\]

IV. PROPOSED METHOD

For more accurate channel estimation with low complexity, the proposed estimator first performs the TD index set estimation from the \( G \times 1 \) CIR estimate \( \hat{h} = \frac{1}{P(F_{P,G})}H_{Q_{F_{P,NY}}} \) and then the TD post-processing with the leakage nulling matrix \( P \) to suppress the leakage as follows in the given two stages as which is shown below

\( i \) Threshold setting and TD index set estimation

Let \( L = (F_{P,G}H_{Q_{F_{P,NY}}}) \) BE THE \( G \times G \) leakage matrix with

\[
\begin{bmatrix} L \end{bmatrix}_{m,n} = \exp \left( -j \frac{\pi (m-n)}{N} \right) \frac{\sin \left( \frac{\pi (m-n)}{N} \right)}{2} \tag{5}
\]

Then, with virtual subcarriers (i.e., \( V \neq 0 \) and \( N \neq U \)), the \( G \times 1 \) CIR estimate is obtained as

\[
\hat{h} = \frac{1}{P(F_{P,G})}H_{Q_{F_{P,NY}}} = h + l + w \tag{5}
\]

Where \( L = (1/p)Lh \) denotes the \( G \times 1 \) leakage vector with \( G \times G \) covariance matrix \( R_{LL} = E[l(l)^H] = 1/p^2 \ LRL^H \). However, the accuracy of the MST selection with virtual subcarriers is severely degraded due to the distortion caused by the leakage. Also, the leakage remains in the selected MST so that an error floor occurs unless a proper processing for the leakage is performed. To overcome the above problems, the proposed MST selection scheme is composed of the two steps as show in algorithm: an initial index set estimation with the initial threshold \( y_i \) to reduce the number of candidates (\( |\Omega_c| < |\Omega_d| \)) followed by a recursive MST selection with a successive leakage cancellation to determine the TD index set \( \Omega_T \) with the following algorithm as that involves various steps and while loops which finally calculates the initial value as follows.

1. Initialization step: \( \Omega_T \leftarrow \phi \)

2. First step (candidate index set estimation)
   \( \Omega_T \leftarrow (\hat{h}) \)

3. Second step (recursion); while
   \( k \leftarrow \text{arg max}_{n \in \Omega_c} |\hat{h}(n)| \)

5. If \( |\hat{h}(k)| > y_i, \Omega_c \leftarrow \Omega_c \setminus \{k\}, \Omega_T \leftarrow \Omega_T \setminus \{k\} \), and \( \hat{h}(j) \leftarrow \hat{h}(j) - \frac{1}{p} \hat{h}(k)[L]_{j,k} \) for \( j \in \Omega_c \{k\} \)

6. else break

7. end while

Similarly as shown under these assumptions, the initial threshold is obtained as

\[
y_i = \sqrt{\frac{1}{L} \frac{1}{P^2 \text{tr}(L^H)}} \text{tr}(L^H) + \frac{1}{\rho P} \ln \left( \frac{1}{1 - \rho MD} \right) \tag{6}
\]
In Step 2, a successive MST selection and leakage cancellation is done with the recursive threshold \( \gamma_r \).

By assuming that the leakage is sufficiently suppressed, the recursive threshold is given by

\[
\gamma_r = \sqrt{\frac{\ln\left(\frac{(G-L)p}{1-L}\right)}{\rho P - L}} \quad (7)
\]

(ii) Time-Domain Post processing

The regularization-based TD post processing matrix for a given constant SNR \( \rho \) is generated from the TD index set \( \Omega_T \) obtained as

\[
P = P\left[(F_{P,T})^H F_{P,T} + |\Omega_T|^2/\bar{\rho}_{|\Omega_T|}\right]^{-1} \quad (8)
\]

V. SIMULATION RESULTS

![Fig 1: MSE performance versus SNR \( \rho \).](image1)

![Fig 2: Achievable rate versus SNR \( \rho \).](image2)

![Fig 3: Portion of virtual sub carriers Vs No. of complex Multiplications.](image3)

![Fig 4: Portion of virtual sub carriers Vs MSE](image4)
CONCLUSION

Channel estimation is a challenging task in the orthogonal frequency division multiplexing. DFT Based Channel Estimation for OFDM Systems that maintains Complexity-Performance Trade-Offs and with leakage suppression using virtual subcarriers. The process we use in this proposed approach is initially starts with time domain (TD) index set estimation considering the leakage effect then followed by low-complexity TD post-processing to suppress the leakage. The proposed channel estimator approach outperforms the existing channel estimators in terms of efficiency and performance.

REFERENCES


Authors Biography

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