Time Domain Pilot-Based Channel Estimation (TDPCE) Using Kalman Filtering for OFDM System

Huda A Abbood1, Hasan F Khazal2 and Thamer M Jamel3

1 College of Engineering Dept, University of Wasit, Wasit, Iraq,
2 College of Engineering Dept, University of Wasit, Wasit, Iraq,
3 Communication Engineering Dept, University of Technology, Baghdad, Iraq,

*Corresponding author E-mail address: habbood@uowasit.edu.iq

Abstract. This work involves using the OFDM technique with the Time domain pilot-based channel estimation (TDPCE) to mitigate the effects of severe channel conditions such as fast and selective fading Raleigh channel with maximum Doppler shift equal to (120 Hz). The propose method has good robust performance, as compared to frequency domain channel estimation approaches. This method is based on comb pilot and Kalman filtering adaptive algorithm. Three digital modulation techniques including Quadrature Amplitude Modulation QAM 16, 32, and 64 were used in the OFDM transmitter with Rayleigh fading multipath channel. The OFDM performance was evaluated by measuring the bit error rate (BER) and the mean square deviation (MSD). Through simulation results, the (BER) has reached (0.0004, 0.004, and 0.01) when (Eb/No) is equal to (12 dB) using QAM 16, 32, and 64, respectively. Also, the convergence rate has almost reached (50, 50, and 125) iterations for the aforementioned QAM's. These results can be taken into consideration as acceptable results in this paper compared to other results in the presence of severe conditions, where the value of maximum Doppler shift parameter of Rayleigh multipath fading channel is (120 Hz) or the user is available in a moving position.

Keywords: Channel Estimation, Kalman Filter, OFDM, QAM, and Rayleigh Channel

1. Introduction
Orthogonal frequency-division multiplexing (OFDM) is a prevalent technique that is used currently because it meets the consumer requirements for common communications services like voice, video sharing, and video conferencing, etc. User specifications are to get a very low BER error rate, low delay / high speed, low packet loss, and higher data rate transfer in comparison to other technologies that are employed in communication network services. Several methods are available to mitigate the effects of inter-symbol interference (ISI) and inter-carrier interference (ICI), including guard interval, cyclic prefix, and orthogonality. For multipath fading networks, however, not all of the above-mentioned techniques are required [1].
Estimation of channels can be performed in both the time and frequency domain. Frequency domain channel estimation techniques perform very well, at the expense of high complication [1]. Therefore, to enhance the performance even more with less complication, channel estimation is achieved in the time domain.[2]. Accordingly, time-domain pilot-based channel estimation (TDPCE) is utilized for channel estimation to reduce the influence of multi-path fast and selective fading channel in the wireless communication system. For this reason, Time Domain Pilot based Channel Estimation (TDPCE) method in the wireless communication system (OFDM) is investigated and software is implemented.

This method is based on comb pilot and Kalman filtering adaptive algorithm which was widely used for channel estimation [3][4]. The main contribution of this paper was using TDPLC with Kalman filtering to achieve good performance for severing channel conditions with maximum Doppler shift equal to 120 Hz (fast varying channel) and frequency selective fading with AWGN. Therefore, this proposed method is considered robust, effective, and recommended to be used for such a multipath Rayleigh fading channel. The OFDM transceiver system with different modulation schemes such as (16QAM, 32QAM, and 64QAM) is simulated by using MATLAB software as a "code" (M file). The transmitted OFDM signal passes through a time-varying multipath Rayleigh fading channel and suffers from fast and frequency selective fading with the Doppler effect. This multipath fading channel and Kalman filter were modeled and represented in the state-space domain. The simulation results were compared with the theoretical BER. The results indicated that the proposed scheme was generated near-ideal accuracy for all SNR regimes.

The subsections of this paper present the concept of TDPCE in Section 2, while Section 3 presents the methodology of the proposed OFDM system with TDPCE. The numerical results are presented in Section 4 while the concluding remarks are finally stated in Section 5.

2. Concept of Time Domain Pilot-Based Channel Estimation (TDPCE)

TDPCE method estimates the channel coefficients with pre-specified length as the actual propagation of the Rayleigh fading channel [5]. In the TDPCE method, the direct channel features are estimated in the time domain. Thus, the calculation time, latency, and computational complication can be much lower than that of the other methods. Therefore, the TDPCE method is effective, strong, and simple [6]. Usually, the channel state information (CSI) can be estimated by using pilots, and eventually, the transmitted symbols can be recovered accurately.

In practice, the CSI is not readily available, and its statistical characteristics vary with the environment. Therefore, adaptive filters are used in the channel estimation stage [7]. According to the time-varying channel, the adaptive channel estimation algorithm tunes its coefficients to keep track of the variations of the channel. The multipath communications channel estimation scheme is proposed to equalize the channel directly as the inverse of the channel frequency response is not required. Figure 1 illustrates the TDPCE system that was proposed by Widrow in [8].

The objective of employing TDPCE is to estimate channel impulse response with adaptive filtering, by modeling the multipath features of the channel that might be achieved employing the system that is shown in Fig. 1 [8]. In this case, a single known pseudorandom sequence (P/N) called ‘PILOT’ is sent cyclically into the channel. The channel output is monitored at the receiving side. The output of the adaptive filter is compared to the channel output, which in this case is the desired response. The filter is adapted to minimize mean-square error (MSE) and in turns reduces mean square deviation (MSD).
More extensive strategy and technique for channel modeling during actual data transmission are proposed by Widrow as shown in Fig. 2 [8]. The sent signal is composed of ZEROs and ONE’s sequences that represent the data. At the receiver side, locally generated synchronized ZEROs and ONE’s sequences are gathered and fed to the adaptive modeling filter, whose output is compared to the signal emerging from the multipath channel. The filter is adapted to make the best least-squares identical to the channel output. The scheme of Fig. 2 was invented by Michael J. Ball as mentioned by Widrow [8].

Figure 3 shows the proposal TDPCE with the Orthogonal Frequency Domain Multiplexing (OFDM) receiver. In the OFDM receiver, the data is passed through a processing element which extracts the cycle prefix (CP) from the signal. Thus, the signal can be processed by TDPCE employing Kalman filtering, which takes advantage of the pilot signal to generate a model of the channel impulse response as shown in Fig. 4.
3. TDPC Methodology:

Figure 5 shows a flow chart of the proposed Time Domain Pilot-based Kalman Filtering of an OFDM system. The transmitted OFDM signal “x6” is passed through the Rayleigh Fading channel and summed with an Additive White Gaussian Noise (AWGN). The flow chart in Figure 5 describes the proposed general steps in this method. The notations used in this research are defined as below:

- \( x_6 \) is the serial transmitted data stream that contains the data, cyclic prefix, and comb-type pilot.
- Rayleigh channel is used to treat the multipath fading for the \( x_6 \) signal and contains main parameters such as sample rate, path delays, average path gains, and maximum Doppler shift.
- \( rw \) is the output signal from the Rayleigh channel.

The signal ‘tt’ represents the result of the distinction between the transmitted OFDM and the output signal from the Rayleigh channel. The output signal ‘txnoise’ comes from the Rayleigh channel which is summed with the Additive White Gaussian Noise (AWGN).
4. Simulation Results

4.1 System Parameters:
The proposed TDPCE for an OFDM system shown in Fig. 3 was simulated according to the flow chart shown in Fig. 5 and the step sequence of Kalman filtering required to estimate the channel coefficients are summarized in Table 1. Moreover, the OFDM system parameters are chosen in accordance with the IEEE 802.11a specifications and are summarized in Table 2. It is assumed that the system holds a perfect synchronization since the aim is to observe channel estimation performance.

4.2 Channel model:
The transmitted signal passes through the Rayleigh fading channel with two multi-path fading Rayleigh channel models and a maximum Doppler frequency of (120 Hz). The Doppler frequency value represents the maximum Doppler shift may the signal suffered when the receiver inside a car that moves on a freeway which matches to a mobile speed of 30 m/s. Therefore, the transmitted signal will suffer from fast and frequency selective fading due to the Doppler shift and the multipath, respectively.

Figure 5. Flow chart of Channel Estimation using Kalman Filter with Rayleigh and AWGN Channel model.

4.3 Results
Fig. 6 represents the actual channel coefficient weight number 3 and its estimated coefficient using the Kalman filter. In Fig 7, the estimated signal of coefficient 3 which represents the output coefficient of Kalman filter (m) oscillates at the beginning especially when the number of iterations starts from 0 to almost
Then the estimated signal starts to be stable (steady-state) and it is fully identical to the actual signal. Meanwhile, Fig 7 exhibits Mean Square Deviation for three types of QAM modulation. MSD is defined as the mean square estimation error between anonymous multipath channel weight coefficients of the communication system and the corresponding Kalman weight coefficients estimation. The convergence rate for both 16QAM and 32QAM are 50 iterations, while the convergence rate for 64QAM has almost reached 125 iterations.

Also, Fig 8, 9, and 10 show the actual BER compared with theoretical BER when using QAM 16, 32, and 64, respectively. The simulation results that compared between estimation and the theoretical BER indicate that the proposed scheme generates near-ideal accuracy for all SNR regimes and this in turn proves or confirms that the proposal TDPCE using Kalman filtering can track the sever channel conditions and introduces good performance even with high Doppler shift that is equal to (120 Hz). Also, it can minimize the inter symbol interference (ISI) effect.

**Table 1. Summarized Kalman filtering algorithm**

| Step | Equation |
|------|----------|
| 1. | $x_n = F_{n-1} x_{n-1} + v_n, y_n = H_n x_n + w_n$ |
| 2. | The conditional pdfs $p(x_n|x_{n-1})$ and $p(y_n|x_n)$ of the state and measurement vectors, respectively, are then presented by the Gaussian pdfs $p(x_n|x_{n-1}) = \mathcal{N}(x_n; F_{n} x_{n-1}, Q_n)$, $p(y_n|x_n) = \mathcal{N}(y_n; H_n x_{n}, R_n)$ |
| 3. | $m_{n|n-1} = F_n m_{n-1|n-1}$, $P_{n|n-1} = F_n P_{n-1|n-1} F_n^T + Q_n$ |
| 4. | $S_n = H_n P_{n|n-1} H_n^T + R_n$, $K_n = P_{n|n-1} H_n^T S_n^{-1}$, $m_{n|n} = m_{n|n-1} + K_n (y_n - H_n m_{n|n})$, $P_{n|n} = P_{n|n-1} - K_n H_n P_{n|n-1}$ |

**Definition [9]:**
- $F_n$ is the $D \times D$ state-transition matrix
- $v_n$ is a $D \times 1$ Gaussian random state noise vector with zero mean
- $Q_n$ is covariance matrix
- $H_n$ is the $M \times D$ measurement matrix
- $w_n$ is an $M \times 1$ Gaussian random measurement noise vector with zero mean
- $R_n$ is covariance matrix
Table 2. Simulation Parameters of OFDM System

| Variable   | Value                        | Description                              |
|------------|------------------------------|------------------------------------------|
| FFT        | 256                          | Fast Fourier Transform size              |
| $f_c$      | 900 MHz                      | Carrier Frequency                        |
| $W$        | 20 MHz                       | Channel Bandwidth                        |
| SampleRate | 5.7 MHz                      | Sampling rate                            |
| nBlocks    | 14 Blocks (Columns)          | No. of Blocks                            |
| Ble        | 16 symbols (Rows)            | Block length                             |
| CP         | 1 block size (16x1), each block has 16 data values | Cyclic Prefix                            |
| NP         | 45                           | No. of Pilots using Comb type pilot      |
| Chan       | Channel                      | Rayleigh Fading Channel                  |
| CL         | 285                          | Channel Length                           |
| FL         | 285                          | Filter Length                            |
| $f_m$      | 120 Hz                       | Maximum Doppler Shift                    |
| D          | [0 1.75e-6] sec              | Multipath Delay vector / two paths       |
| G          | [0 -3] dB                    | Multipath Gain vector / two paths        |
| Initial Coefficients | 285 of Zeros | Initial coefficients of (KF) algorithm 285x1 |

Figure 6. Theoretical and estimation coefficient for weight number 3

Figure 7. MSD for QAM16, QAM32, QAM64
Consequently, Fig 11 shows that the estimated BER for the QAM16 curve is better than that of the estimated BER for both QAM32, and QAM64, respectively. Table 3 shows the comparison between the estimated BER using QAM 16, 32, and 64.

| Curve     | Estimated BER QAM16 | Estimated BER QAM32 | Estimated BER QAM64 |
|-----------|---------------------|---------------------|---------------------|
| Max BER   | 1e-1                | 2e-1                | 2e-1                |
| EbNo      | 0                   | 0                   | 0                   |
| Min BER   | 4e-4                | 4 e-3               | 1e-2                |
| EbNo      | 12                  | 12                  | 12                  |
Finally, Table 4 illustrates a comparison of a proposed system results with other related works [10][11]. As shown in this table our proposed method has a better performance compared with ref [11] despite using doppler frequency 120 Hz instead of 100 Hz, and on the other hand ref [10] has better performance than our method due to they used both lower carrier frequency (0.626 GHz) and doppler frequency.

| OFDM Sys Design       | Channel Model                      | Doppler Freq (Hz) | Max Vehicular Speed (Km/h) | BER (bit/sec) Freq Carrier $f_c$ (GHz) |
|-----------------------|------------------------------------|-------------------|----------------------------|---------------------------------------|
| TDPCE In this paper   | Rayleigh Fading Multipath Channel  | 120 Hz            | 142.56 Km/h                | QAM16 $= 4 \times 10^{-4}$ QAM32 $= 4 \times 10^{-3}$ QAM64 $= 1 \times 10^{-2}$ 900MHz |
| Frequency Domain Adaptive Equalization of Multipath Fast Fading Channel Proposed method [11] | Rayleigh Fading Multipath Channel (3 Paths) | 100 Hz | 118.8 Km/h | QAM16 $= 7 \times 10^{-2}$ QAM64 $= 2 \times 10^{-1}$ BPSK $= 1 \times 10^{-2}$ QPSK $= 1 \times 10^{-2}$ 900 MHz |
| Pilot-Based Time Domain (PTD) SNR Estimation Proposed Method [10] | Rayleigh Fading Multipath Channel (6 Paths) | 28.98 Hz | 50 Km/h | QAM16 $= 2 \times 10^{-5}$ 0.626 GHz |

5. Conclusion

In this paper, time-domain pilot-based channel estimation (TDPCE) is evaluated which was based on comb pilot and Kalman filtering for the OFDM system to estimate the time-varying multipath Rayleigh fading channel and AWGN with various M-QAM modulation schemes. The transmitted signal has suffered from and frequency selective and fast fading due to multipath and Doppler shift, respectively. From the simulation results, it is found that the (BER) has reached $(4e^{-4})$ for 16QAM, $(4e^{-3})$ for 32QAM, and $(1e^{-2})$ for 64QAM (Eb/No) equal to (12 dB). Moreover, the MSD has fast convergence for 16 QAM, then will be slow down for both 32QAM and 64 QAM, respectively.

The system with the proposed TDPCE method introduces good performance even with a high Doppler shift that is equal to (120 Hz). The simulation results prove that Time Domain Pilot based Kalman Filtering for channel estimation is suitable for tracking time-varying multipath Rayleigh channels.

6. References

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