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A New Study of Channel Estimation Methods for OFDM in DVB-T2

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Abstract

In this paper three proposed methods of channel estimation are introduced. These methods are based on pilot-aided OFDM system with the arrangement employed in the DVB-T2 standard in time-varying frequency-selective fading channels. The first and second methods (low complexity and improved low complexity methods, respectively) are modified methods based on Domain Transform Least Square Estimation (DTLSE) method; which reduce the computational complexity by avoiding the use of the matrix inversion. The estimation matrix size for obtaining Channel Impulse Response (CIR) depends only on the length of the channel rather than the number of pilot sub-carriers or the size of OFDM symbols. The third method (high performance method), which is based on the first proposed method and a Two Dimensional Linear Interpolation 2-DIL method, uses one frame instead of one symbol and offers lesser complexity than the MMSE method, and a BER performance close to it.

Keywords: Digital Video Broadcasting System for Terrestrial Second Generation (DVB-T2); DomainTransform Least Square Estimation (DTLSE); Two Dimensional Linear Interpolation (2-DLI); Minimum Mean Square Estimation (MMSE).

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1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier transmission technique in wireless environments, and can be seen as a multi-carrier digital modulation or multi-carrier digital multiplexing one as well. A large number of orthogonal sub-carriers are used to transmit information. OFDM systems have high utilization of the frequency spectrum and satisfactory capabilities of reducing multi-path interference. The main advantage of OFDM is its immunity to frequency selective fading by dividing the wideband channel into a series of narrowband channels, thus each experiences flat fading. Therefore only one tap equalizer is required in the receiver, reducing complexity greatly [1-2]. OFDM has been adopted by several wireless systems and standards such as WLAN IEEE802.11a/n, 4G LTE, WiMAX IEEE802.16d/e, Digital Audio Broadcasting (DAB), Terrestrial Digital Video Broadcasting DVB-T and DVB-T2 [3].

At the OFDM system transmitter side, the Inverse Fast Fourier Transform (IFFT) is used for modulating the data constellations on the orthogonal sub-carriers. These constellations can be taken by grouping and mapping the binary data, according to an M-ary PSK or QAM modulation, such as QPSK or 16-QAM. Then, the pilots are inserted either as a comb type, block type or a compromise of both (e.g. scattered pilots). Finally the Digital to Analog Converter (DAC) is applied for transmitting the signal on the channel. The same operations that took place in the transmitter are repeated at the receiver in reversed order to reproduce the transmitted binary sequence [4, 5].

The channel characteristic, which is the causative? of the channel effects such as attenuation distortion, delay distortion and noise, is compensated by channel estimation at the receiver side. Channel estimation plays a very important role in OFDM systems. It can generally be separated into two methods: pilot-assisted channel estimation and blind channel estimation. Pilot-assisted channel estimation, which is the focus of this paper, performed by transmitting training pilot symbols on sub-carriers these pilots are known to the receiver. The system performance and computational complexity are two important requirements for selecting the optimum technique of the channel estimation [4]. Compared to blind channel estimation, which uses statistical information of the received signals and is not considered in this paper, pilot-based channel estimation is a practical and effective method. Many pilot- assisted channel estimation methods are found in the literature; here some of them are cited [6].

Channel estimation techniques for pilot-assisted OFDM systems can be categorized into three groups. The first group, which is known as Frequency Domain Least Square Estimation (FDLSE) employs the least Squares (LS) estimate at pilot sub-channels position. Then, the complete Channel Transfer Function (CTF) at all subcarriers are calculated from interpolation either in frequency-direction (1-D) only or both time and frequency dire-ctions (2-D). The (2-D) performs better than (1-D) interpolation at the cost of higher sensitivity to Doppler frequency shifts and long processing delay [7, 8].

The second group employs the time-domain sequence of modulated pilot subcarriers to estimate the CIR which is known as the Time Domain Least Square Estimation (TDLSE) [9]. The last technique employs LS estimates of pilot sub-channels to estimate the time-domain Channel Impulse Response (CIR) and its subsequent transformation to CTF which is known as the DTLSE [10]. One of the FDLSE techniques is the MMSE estimation method [11] which offers the best BER and Mean Square Error (MSE) performance. However, it requires perfect timing synchronization, the knowledge of channel statistics (such as channel power delay profile) and a heavy computational load.

The proposed low complexity method needs a single OFDM symbol for getting channel impulse response instead of multiple ones. It also works for any frequency pilot pattern without needing prior knowledge of channel statistics while in the same time considerably reducing the computational load through avoiding the use of matrix inversion. It is also worth mentioning that the size of the estimation matrix for obtaining CIR depends only on the length of the channel not the number of pilot subcarriers or the size of OFDM symbol.

The proposed improved low complexity method which uses all symbols in the frame for channel estimation has the same advantages of low complexity method, but the computational load will increase slightly by the number of symbols used. The proposed high performance method which is based on the proposed low complexity and (2-DLI) methods gives better performance than the first low complexity method and reduces the computational complexity than the MMSE method. The estimation matrix for obtaining CIR depends only on the length of the channel. It also works for any frequency pilot pattern without the need of prior knowledge of channel statistics.

The three proposed methods are compared with three other methods: DTLSE, 2-DLI and Minimum Mean Squared Error (MMSE). The first and second proposed methods prove to be less complex, with less computational load than the DTLSE and MMSE methods, and have higher robustness to Doppler shifts than the 2-DLI method; also the second method proves to give BER performance comparable to MMSE method. The third method offers lesser complexity than the MMSE method, and a BER performance close to it and substantially better than the first proposed, DTLSE and 2-DLI methods.

The paper is organized as follows; the system description and principle of channel estimation are explained in section (1.1); performance analysis of the considered methods are presented in section (1.2); computational load of the considered methods are calculated in section (1.3); the simulation results are presented in section (1.4); The results for the BER Performance of the proposed methods for different Pilot Patterns are presented in section (1.5), while section (1.6) concludes the paper.

1.1. System descriptions

A general baseband OFDM system is used in this paper, over a frequency-selective fading channel through a single transmitter and receiver antenna. In each frequency-domain OFDM symbol X, there are N subcarriers independently modulated by either a pilot or data. Within a typical OFDM system receiver, after removing the guard interval, demodulation is performed by FFT. When the length of the guard interval is longer than the length of the CIR, the ISI can be eliminated. In this case, a single channel can be viewed as a set of parallel sub-channels and the received signal is represented by

$$Y_N = H_N X_N + W_N \qquad (1)$$

where Y_N represents the received signal in complex baseband (frequency domain), X_N denotes the transmitted signal, H_N and W_N are the CFR and the AWGN, respectively. N is the total number of sub-carriers within an OFDM symbol [12,13].Channel estimation with the aid of pilots in OFDM systems is performed by estimating the Channel Frequency Response (CFR) at the pilot locations. This is obtained by comparing the received pilot sub-carriers with the transmitted one which are known to the receiver. Let N_P be the total number of pilots, the estimation of the CFR at a pilot position can be obtained by the LS method as follows:

$$\widehat{H}_{N_P} = \frac{Y_{N_P}}{X_{N_P}} = H_{N_P} + \frac{W_{N_P}}{X_{N_P}} \qquad (2)$$

where Y_{N_P} denotes the received pilot sub-carrier, X_{N_P} is the transmitted pilot sub-carrier, and, $\widehat{H}_{N_P}$ is the estimation of CFR at the pilot position. The CFR values at the rest of the subcarriers are then calculated from the estimated ones via interpolation [15]. After interpolation of channel coefficients at all data subcarriers the complex received signal is equalized as:

$$\widehat{X}_N = \frac{Y_N}{\widehat{H}_N} \qquad (3)$$

where $\widehat{H}_N$ denotes the estimated and interpolated CFR at all indices and $\widehat{X}_N$ is the estimated transmitted signal. In DVB-T2 system for 1024 Subcarriers (1K-mode), the scattered pilot patterns used for channel estimation (from pilot patterns PP1to PP5), are spread in both frequency directions D_x and time directions D_y. As shown in Table 1, where D_x is the difference in carrier index between adjacent scattered-pilot-bearing carriers and D_y is the Difference in symbol number between successive scattered pilots on a given carrier [14].

Table 1: Parameters defining the scattered pilot patterns in 1K-mode

Pilot pattern	D_X	D_Y
PP1	3	4
PP2	6	2
PP3	6	4
PP4	12	2
PP5	12	4

In the following section the performance analysis of the considered methods compared with other methods will be introduced.

1.2. Performance analysis of the considered methods

In this section, six channel estimation methods are presented. The first three of them are already published in the literature while fourth, fifth and the sixth are new proposed algorithms.

1.2.1. 2-DLI Method

In this method [7], the CFR at the pilot positions are calculated at the N_P^{th} pilot subcarrier and n_P^{th} OFDM symbol as

$$\widehat{H}_{n_p,N_p} = \frac{Y_{n_P,N_P}}{X_{n_P,N_P}} = H_{n_p,N_p} + \frac{W_{n_P,N_P}}{X_{n_P,N_P}} \quad (4)$$

The CFR values $(\widehat{H}_{n,k})$ at the rest of the subcarriers are calculated from the estimation via interpolation which is applied in both frequency direction (across subcarriers) and time direction (across successive OFDM symbols). At first, interpolation has to be performed in time direction then interpolation is performed in frequency direction to obtain channel coefficients for the remaining data subcarriers. The most common interpolation method is the linear Interpolation (LI) because of its simplicity and low computational complexity. After and more interpolation of channel coefficients at all data subcarriers the complex received signal is equalized as

$$\widehat{X}_{n,N} = \frac{Y_{n,N}}{\widehat{H}_{n,N}} \quad (5)$$

where $Y_{n,N}$ is the complex received signal FFT outputs, $\widehat{H}_{n,N}$ denotes the estimated and interpolated CFR at all indices and $\widehat{X}_{n,N}$ is the estimated transmitted signal. This method suffers from long processing delay and sensitivity to Doppler frequency shifts [7].

1.2.2. DTLSE Method

In DTLSE method [10], the least square estimation of pilot sub-channels is employed to estimate time-domain CIR and then transform it to CTF. The CIR is then given as [10]:

$$\widehat{h}_{N_p} = (F_{N_P,N_P}^H F_{N_P,N_P} + \alpha I_{N_P,N_P})^{-1}. F_{N_P,N_P}^H . \widehat{H}_{N_P} \quad (6)$$

where F_{N_P,N_P} is a $N_P \times N_P$ Fourier transform coefficients matrix, I_{N_P,N_P} is an $N_P \times N_P$identity matrix and α is a regularization parameter (The choice of α will be discussed in section a) [15]. The whole effective CTF is estimated by applying N-point FFT on the zero padded estimated effective CIR. In this method the size of the estimation matrix for obtaining CIR only depends on the number of pilot subcarriers, but not on the size of OFDM symbol. It has many properties as:

- It uses only one OFDM symbol,
- It does not require knowledge of channel statistics,
- It works for any pilot pattern.

1.2.3. The MMSE Method

The MMSE estimation [11], provides the best BER performance. It estimates CTF $\widehat{H}_{mmse}$as

$$\widehat{H}_{mmse} = R_{N,N_p}.R_{N_p,N_p}^{-1/2}.R_{N_p,N_p}^{-1/2}.\ \widehat{H}_{N_p,ls} \qquad (7)$$

where R_{N,N_p} of size N×N_P is the correlation matrix of complete CTF with pilot sub-channels, and R_{N_P,N_P} of size N_P×N_P is the correlation matrix of pilot subchannels with its LS estim-ate $\widehat{H}_{N_p,ls}$. This method suffers from heavy computational load and needs Prior knowledge of channel statistics.

1.2.4. Proposed Low Complexity Method

The proposed low complexity method [16], which needs only a single OFDM symbol, not multiple ones, for getting the CIR, has many noteworthy properties as: It works for any frequency pilot pattern without needing prior knowledge of channel statistics. It also reduces the computational load by avoiding the use of matrix inversion and the size of the estimation matrix for obtaining CIR depends only on the length of the channel rather than the number of pilot sub-carriers or the size of the OFDM symbol. In this proposed method [16], the use of inverse matrices is avoided as will be shown. Based on (2) the received pilot sub-carriers can be defined as:

$$Y_{N_P} = \widehat{H}_{N_P}.X_{N_P} \qquad (8\text{-a})$$

$$= D(X_{N_P}).F_{N_P,L}.\hat{h}_L \qquad (8\text{-b})$$

where $\widehat{H}_{N_P} = F_{N_P,L}.\hat{h}_L$, $\hat{h}_L$ is the CIR, $F_{N_P,L}$ is the FFT coefficients matrix of size N_P×L, L is the length of the channel and $D(X_{N_P})$ is a diagonal matrix with X_{N_P} on its diagonal. Then by using the least square solution [17], the CIR $\hat{h}_L$ is obtained as:

$$\hat{h}_L = ((D(X_{N_P}).F_{N_P,L})^H.D(X_{N_P}).F_{N_P,L})^{-1}.(D(X_{N_P}).F_{N_P,L})^H.Y_{N_P}$$

$$= (F_{N_P,L}^H.D\big(X_{N_P}\big)^H.D\big(X_{N_P}\big).F_{N_P,L}\big)^{-1}.(D\big(X_{N_P}\big).F_{N_P,L})^H.Y_{N_P} \qquad (9)$$

where $(.)^{-1}$ denotes matrix inverse and $(.)^H$ denotes Hermitian transpose.

Using the fact that $D(X_{N_P})^H.D(X_{N_P}) = I_{N_P,N_P}$, where I_{N_P,N_P} is the identity matrix of size $N_P \times N_P$.

$$\hat{h}_L = (\ F_{N_P,L}^H.I_{N_P,N_P}.F_{N_P,L})^{-1}.(D(X_{N_P}).F_{N_P,L})^H.Y_{N_P}$$

$$= (\ F_{N_P,L}^H.F_{N_P,L})^{-1}.(D(X_{N_P}).F_{N_P,L})^H.Y_{N_P} \qquad (10)$$

The $F_{N_P,L}^H.F_{N_P,L} = N_P.I_L$, where I_L is the identity matrix of size $L \times L$ so that h_L is given as

$$\hat{h}_L = (\ N_P.I_L)^{-1}.(D(X_{N_P}).F_{N_P,L})^H.Y_{N_P}$$

$$= (\frac{1}{N_P}) I_L . F_{N_P,L}^H . D(X_{N_P})^H . Y_{N_P} \quad (11)$$

based on (11) the size of the estimation matrix $\hat{h}_L$ for obtaining the CIR only depends on the length of the channel and the use of inverse matrices is avoided. The whole effective CTF is estimated by applying N-point FFT on the zero padded estimated effective CIR.

1.2.5. Proposed Improved Low Complexity Method

The proposed low complexity method [16], needs only a single OFDM symbol instead of multiple to get the CIR. It provides similar channel estimation BER performance as the DTLSE method, but it provides SNR values 2.5 dB away from that with perfect channel estimation at the same BER. This difference is possibly reduced by using all symbols in the frame for channel estimation instead of one symbol, which is used in the proposed improved low complexity method. This leads to a significant improvement in performance (comparable to perfect channel estimation). This method has many common properties with the low complexity method, but the difference is that the computational load will increase slightly by the number of symbols used.

1.2.6. Proposed High Performance Method

The proposed high performance method [18], which is based on the proposed low complexity and 2-DI methods gives better performance than the first proposed method and reduces the computational complexity compared to the MMSE method. The estimation matrix for obtaining CIR depends only on the length of the channel. It also works for any frequency pilot pattern without need of prior knowledge of channel statistics. For slow-fading channels, it can be assumed that the channel coefficients at a sub-carrier throughout several OFDM symbols remain approximately constant. Based on (8-b) the two dimensional estimation matrix of CFR can be obtained by the LS method as [17]:

$$\hat{H}_{L,L} = X_{L,N_P}^{-1} . Y_{N_P,L} \quad (12)$$

where $\hat{H}_{L,L}$ is L×L CFR estimation matrix, X_{L,N_P} is L×N_P transmitted matrix and $Y_{N_P,L}$ is N_P×L received matrix. By applying the least square solution the CFR estimation matrix is given as

$$\hat{H}_{L,L} = (X_{N_P,L}^H . X_{N_P,L})^{-1} . X_{N_P,L}^H . Y_{N_P,L} \quad (13)$$

The noise in $\hat{H}_{L,L}$ will be severely amplified by X^{-1}, leading to an estimate of CFR far away from its actual value. This problem can be solved by Tikhonov regularization [15] as:

$$\hat{H}_{L,L} = \left(X_{N_P,L}^H . X_{N_P,L} + \alpha I_{L,L}\right)^{-1} . X_{N_P,L}^H . Y_{N_P,L} \quad (14)$$

where I is the L×L identity matrix and α is a regularization parameter. The choice of α can be obtained using, the L-curve method [15] as will be explained in sub-section a. Based on the concept used in (11) and because $\hat{h} = F^{-1}\hat{H}$ (where F^{-1} the inverse of FFT coefficients matrix) so, the CIR $\hat{h}_{L,L}$ can be obtained as

$$\hat{h}_{L,L} = (\frac{1}{N_P}) I_{L,L}. F_{L,L}^H. \hat{H}_{L,L} \quad (15)$$

where $\hat{h}_{L,L}$ is L×L CIR estimation matrix,$F_{L,L}$ is the fast Fourier transform coefficients matrix of size L×L .So, from (14) and (15) the CIR is then given as

$$\hat{h}_{L,L} = (\frac{1}{N_P}) I_{L,L}. F_{L,L}^H. ((X_{N_P,L}^H. X_{N_P,L} + \alpha I_{L,L})^{-1}. X_{N_P,L}^H. Y_{N_P,L}) \quad (16)$$

based on (16) the size of the estimation matrix $\hat{h}_{L,L}$ for obtaining the CIR depends only on the length of the channel. The whole effective CTF is estimated also by applying N-point FFT on the zero padded estimated effective CIR. In the following sub-section the strategy to choose α are shown.

a. L-Curve Method

Minimizing the estimation errore, highly depends on choosing a proper regularization parameter α [15]. To study the effect of α, we decompose e into two error sources, which are known as regularization error e_r and additive noise error e_n. One strategy to balance these two errors is called the L-curve method [15]. It plots $E[e_r]$ and $E[e_n]$ under different α's to graphically search for a tradeoff point, which minimizes $E[e_r] + E[e_n]$ where E is the expectation operator. An example of this method is shown in Figure1. It is applied to a DVB-T2 OFDM system with 1024 subcarriers, and SNR of (10, 20, 30) dB. The curve is L-shaped, hence its name. According to Figure1, an α around 2 is acceptable.

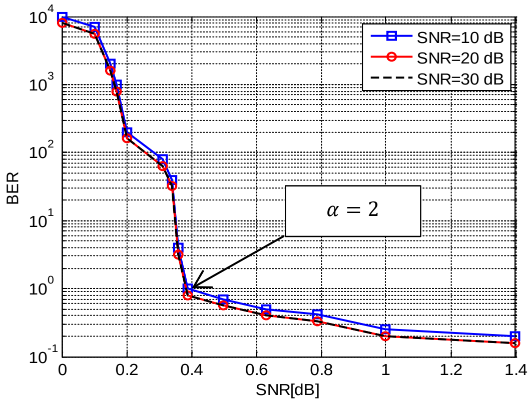

Figure 1: The L-curve method to choose regularization parameter α [15].

1.3. Comparison of computational loads of the considered methods

The computational load or the number of arithmetic operations is an important factor for distinguishing between the methods of channel estimation. In Strassen algorithm [19] the multiplication between an $n_1 \times n_2$ matrix and an $n_2 \times n_3$ matrix requires about $2n_1n_2n_3$ arithmetic operations and the inverse of an $n \times n$ matrix requires about $5.5n^{2.8}$ arithmetic operations. The ratio between the number of sub-carriers and the number of pilots is $\rho = N_p/N$ and L is the length of the channel. In Table 2 and Figure 2, the computational load of MMSE, DTLSE, first, second and third proposed methods are calculated. The 2-DLI computational load is not considered here because it depends on linear interpolations only, which is far less complex than the matrix-based methods.

Table 2: Computational load of the considered methods

Methods	No.of required arithmetic operation
MMSE	$4\rho^2N^3 + 5.5\rho^{2.8}N^{2.8} + 3\rho N^2$
DTLSE	$2\rho^3N^3 + 5.5\rho^{2.8}N^{2.8} + 2\rho^2N^2 + \rho N$
Low Complexity Method	$2L\rho^2N^2 + 2L\rho N$
Improved Low Complexity Method	$4L\rho^2N^2$
High Performance Method	$2(\rho N(L(1 + \rho N) + \rho^2N^2 + \rho N)) + \rho N + 5.5\rho^{2.8}N^{2.8}$

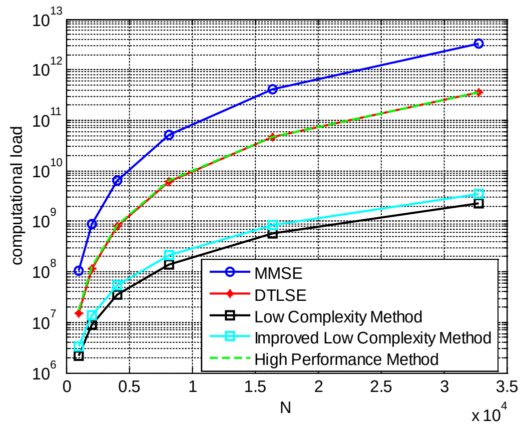

Figure 2: The computational load for the considered methods.

1.4. Simulation results

1.4.1. Low Complexity and improved low complexity Methods

The simulated OFDM system is adopted from DVB-T2 [3] with a bandwidth of 8 MHz. There are 1024 sub-carriers; data sub-carriers are modulated by a quadratic phase-shift keying constellation. In DVB-T2 system for pilot pattern (PP1), the scattered pilots used for channel estimation are spread in both the time and frequency domains as shown in Table 1. There is one pilot sub-carrier out of three sub-carriers in the frequency direction and one pilot out of four symbols in the time direction, with elementary time of T_l = 7/64 μs, and the CP length is 64. Two channel models were investigated in order to evaluate and compare the performance of the low complexity, improved low complexity methods and considered methods under different channel conditions with frequency selectivity. The performance under a slow and a high Doppler frequency shift was also considered.

A typical urban channel profile named TU-6 in [20] is considered. It consists of six taps having a wide dispersion in delay and a relatively strong power. Each of them follows the Jakes' Doppler spectrum [21]. The model in [10] was applied in which the taps are considered to be spaced by a multiple of T_l. The first tap is assumed to be of zero delay, and the channel length is L = 47. Six taps with non-zero power are positioned at j = 0, 2, 5, 15, 21, 46, with powers equal to (-3, 0, -2, -6, -8, -10) dB, respectively. A Brazil-D channel in [22] is also considered; six taps with non-zero power are positioned at j = 0, 5, 20, 29, 57, 58, with powers equal to (-0.1,-3.9,-2.6,-1.3, 0,-2.8) dB, respectively and the channel length is L = 59.

The BER performance of the low complexity and improved low complexity methods were measured and compared to the 2-DLI, DTLSE and MMSE methods under 50-Hz Doppler frequency shift. The low complexity method provides SNR values 2.5 dB away from that with perfect channel estimation at the same BER. This difference is reduced to 1 dB using the improved method and become negligible when applying the MMSE method as shown in Figure 3.

For a high Doppler frequency shift of 300 Hz, The BER results are shown in Fig 4. The low complexity, improved low complexity, DTLSE and MMSE methods provide similar performance as in the case of low Doppler frequency shift. There is a BER error floor for the 2-DLI method which shows that it is not robust to high Doppler frequency shifts. In case of a Brazil-D channel, as shown in Figure 5, the BER of the low complexity , improved low complexity methods and other methods under 50-Hz is slightly higher than that of Figure3. This means that the Brazil channel is more frequency selective than the TU-6 channel. In Figure6, the BER performance of the low complexity and improved low complexity methods with the 2-DLI, DTLSE and MMSE methods under 300-Hz Brazil channel is simulated. The BER of the 2-DLI method is much higher than all methods which provide similar performance as in Figure 5.

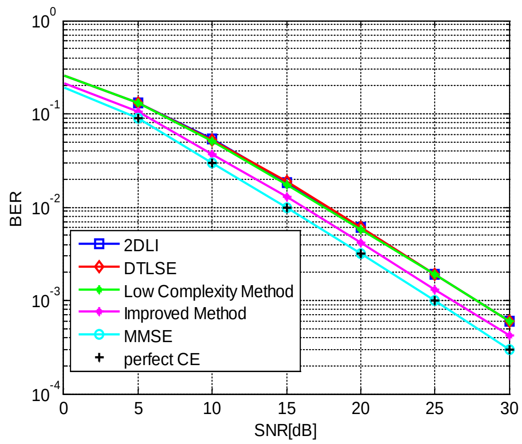

Figure 3: BER vs. SNR for the first, second proposed and other methods under TU-6 channel for 50-Hz Doppler frequency shift.

1.4.2. High Performance Method

The simulated OFDM system is adopted from DVB-T2 [3]. Three channel models were investigated, the TU-6 channel [20] and the Brazil Channel D [22] which were previously mentioned, and the high delay spread Rayleigh fading channel [3] with six taps with non-zero power are positioned at j = 0, 2, 17, 36, 75, 137, and powers equal to (0, -5, -7, -8.8, -10, -10) dB, respectively.

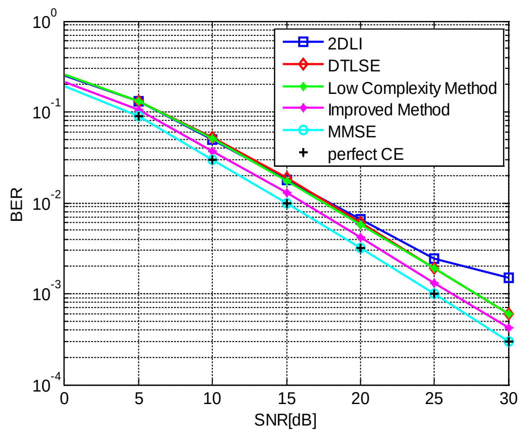

Figure 4: BER vs. SNR for the proposed low complexity, improved methods and other methods under TU-6 channel for 300-Hz Doppler frequency shift.

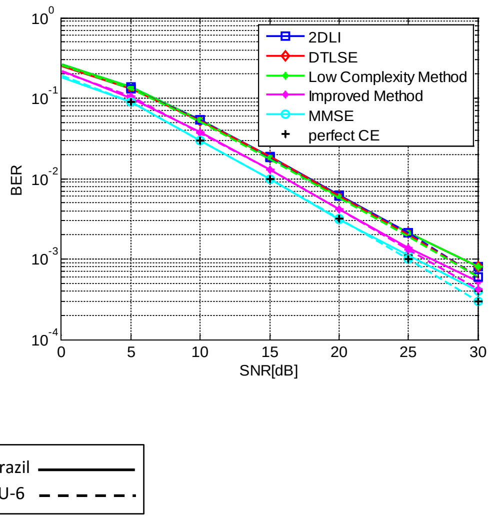

Figure 5: BER vs. SNR for the proposed low complexity, improved methods and other methods under 50-Hz Brazil-D and 50-Hz TU-6 channel.

The BER performance of the High Performance Method was simulated and compared to the low complexity, improved low complexity and MMSE methods. Under TU6 channel conditions the High Performance Method provides on average SNR values 1 dB higher than that with perfect channel estimation and 1.5 dB less than that of the low complexity method at the same BER. This difference is negligible for the MMSE method as shown in Figure 7.

In case of a Brazil-D channel [22], as shown in Figure 8 the BER of the High Performance Method and the other methods are slightly higher than those in TU6. In high delay spread Rayleigh fading channel [3], the BER of the High Performance Method and other methods are severely higher than those in Figure 7 and Figure 8 as shown in Figure 9.

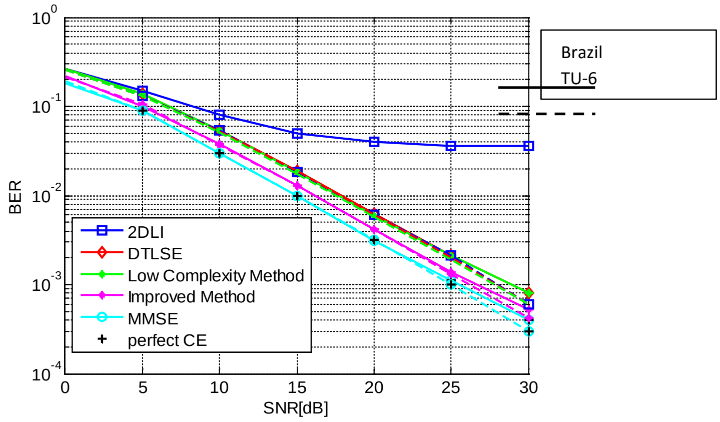

Figure 6: BER vs. SNR for the proposed low complexity, improved methods and other methods under 300-Hz Brazil-D and 50-Hz TU-6 channel.

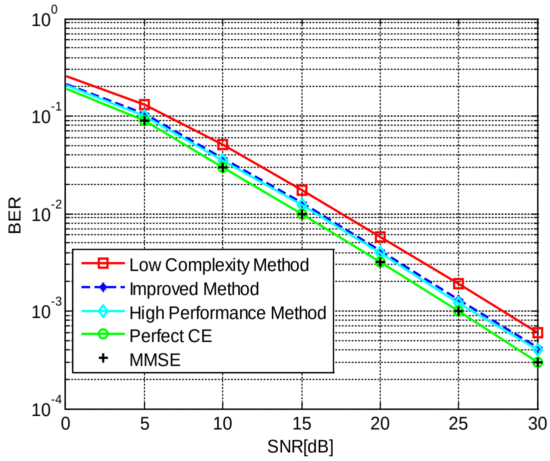

Figure 7: BER vs. SNR for the proposed high performance method and other methods under TU-6 Channel

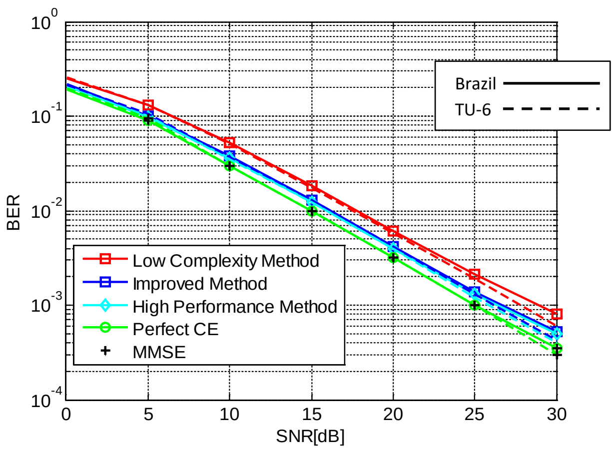

Figure 8: BER vs. SNR for the proposed high performance method and other methods under Brazil-D channel and TU-6 Channel

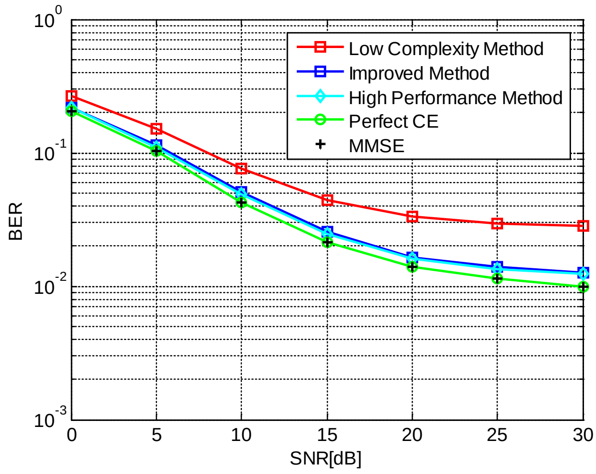

Figure 9: BER vs. SNR for the proposed high performance method and other methods under high delay Rayleigh fading Channel

1.5. Results for the BER Performance of the Proposed Methods for Different Pilot Patterns

In this sub-section the results for the BER performance of the proposed low complexity, proposed improved low complexity and high performance methods under TU-6 channel are introduced. The parameters of the adopted DVB-T2 system pilot patterns (PP1, PP2, PP3, PP4 and PP5) are shown Table 1. The BER performance of these methods provide the same performance for pilot patterns (PP1and PP2) but gives SNR values 5 dB away from them at the same BER, for pilot patterns (PP3 and PP4). This difference will be increased to10 dB for pilot pattern (PP5) as shown in Figure 10. This is because these methods use only one symbol and multiple symbols respectively, the difference in carrier index between adjacent scattered-pilot-bearing carriers in one symbol is the same in pilot patterns (PP1 and PP2) and increased from 11 to 24 for pilot patterns (PP3 and PP4) which also are the same in carrier index difference. This difference increases to 48 in pilot pattern (PP5).

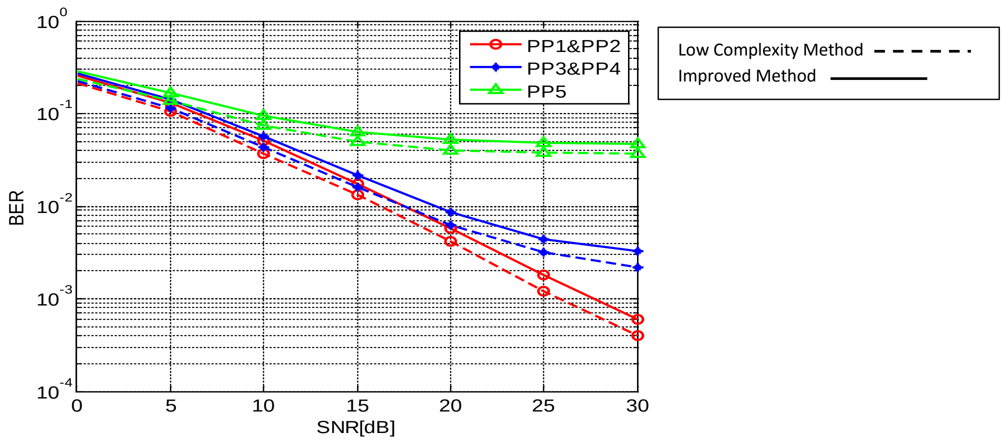

Figure 10: BER vs. SNR of the proposed low complexity, improved methods for considered pilot patterns under TU-6 channel.

In the proposed high performance method, the BER performance for pilot patterns (PP2 and PP3) provides SNR values 2.5 dB away from that in (PP1) at the same BER, but the SNR for pilot patterns (PP4 and PP5) is 7.5 dB away from PP1 at the same BER, as shown in Figure 11. This is because the third method uses one frame and the difference in carrier index between adjacent scattered-pilot-bearing carriers (D_x) increased from 3 in pilot pattern (PP1) to 6 in pilot patterns (PP2 and PP3) which have the same D_x. This increase will be up to 12 in pilot pattern (PP4 and PP5) which again have the same D_x value. The conclusion from this is that, the BER performance changes dramatically for the first and the second methods compared to the third one.

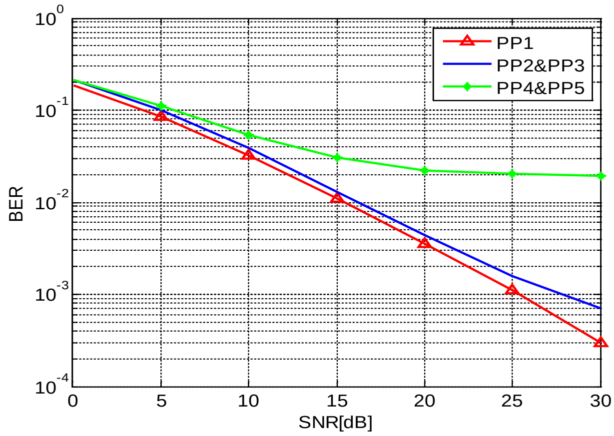

Figure 11: BER vs. SNR of the proposed high performance method for considered pilot patterns under TU-6 channel.

1.6. Conclusion

Three proposed methods of channel estimation were introduced. Most noteworthy about the properties of the first and second proposed methods are: avoidance of matrix inversion, the size of estimation matrix for obtaining the CIR only depends on the length of the channel (i.e. it is independent of the number of pilot sub-carriers nor the size of the OFDM symbol), they use only one OFDM symbol and multiple symbols respectively, work for any frequency pilot pattern and do not require any knowledge of channel statistics. The first proposed method provides similar channel estimation BER performance as the DTLSE method, with less complexity, and is better than the 2-DLI which has less robustness to Doppler frequency shifts. The second proposed method gave BER performance better than the first one (1.5 dB in SNR at the same BER) and comparable to MMSE method. The third proposed method shares the notable properties of the first and second method but differs from these in that it does not avoid matrix inversion and uses one frame instead of one symbol. It provides BER performance better than the first proposed, DTLSE, 2-DLI and closest to the MMSE's, and it has less complexity compared to it.

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