Journal of Engineering and Development, Vol. 15, No. 1, March (2011) **ISSN 1813-7822**

Performance Of Channel Estimation For (OFDM) System Based On Block-Type Pilot Arrangement In Rayleigh Fading Channel

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Abstract

Recently, the superimposed pilot channel estimation has been proposed for wireless communications, where the pilot symbol sequence is superimposed on a data symbol sequence and transmitted together, and thus it has higher spectral efficiency. The channel estimation for orthogonal frequency division multiplexing (OFDM) system based on pilot arrangement over frequency selective Rayleigh fading channel is presented. The estimation of the channel is based on least square (LS) and minimum mean square error (MMSE) estimators. In this work, two schemes of pilot arrangement are proposed; pilot aided form (3) and pilot aided form (1). The bit error rate (BER) performance of superimposed pilot channel estimation is compared with the two proposed schemes by simulation. The simulation results show that the superimposed pilot channel estimation outperforms pilot aided form (3), while pilot aided form (3) outperforms pilot aided form (1) under frequency selective fading channel for both MMSE and LS estimators.

***Keywords:** Channel estimation, Orthogonal Frequency Division Multiplexing (OFDM) system, LS channel estimator, MMSE channel estimator.*

الخلاصة

مؤخرا,تخمين القناة لترتيب الحاملات نوع (superimposed) قد قدمت للاتصالات اللاسلكية, وان ترتيب رموز الحاملات الموجهه نوع(superimposed) ورموز البيانات ترسل سوية وتكون ذات كفاءة طيفية عالية. تخمين القناة بنظام التقسيم الترددي المضاعف المتعامد والمستند على ترتيب الحاملات الموجهه قد اظهرت في قناة الخفوت الانتقائية التردد نوع (Rayleigh) . ان تخمين القناة استند على استخدام خوارزمية التخمين التربيعي الضئيل (LS) والتخمين باقل معدل خطاء تربيعي (MMSE). في هذا العمل ,تم اقتراح تشكيلين مختلفين من ترتيب الرموز الموجهه الاول يسمى التشكيل الثالث للرموز الموجهه (form3) والثاني يسمى التشكيل الاول للرموز الموجهه (form1) وقد تم اختبار اداء نسبه معدل الخطاء (BER) في ترتيب الحاملات الموجهه لتخمين القناة نوع (superimposed) وقورنت مع التشكيلن المقترحين بواسطة نظام التحليل. ان تحليل النتائج اظهر ان تخمين القناة باستخدام ترتيب الحاملات الموجهه نوع (superimposed) يكون افضل بالاداء عن التشكيل الثالث, وان التشكيل الثالث كان افضل بالاداء عن التشكيل الاول في قناة الخفوت الانتقائية التردد بواسطة استخدام خوارزميتي النخمين(LS) وكذالك (MMSE).

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has recently been applied widely in wireless communication systems due to its high data rate transmission capability with high bandwidth efficiency and its robustness to multi-path delay [1]. A dynamic estimation of channel is necessary before the demodulation of OFDM signals since the radio channel is frequency selective and time-varying for wideband mobile communication systems.

The estimation of the channel for this block-type pilot arrangement may be based on Least Square (LS) or Minimum Mean-Square (MMSE) estimators [1] [2].

In [3], the superimposed pilot channel estimation for wireless communications was proposed, where the pilot symbol sequence was superimposed on a data symbol sequence and transmitted together, and thus it has a high spectral efficiency. In this scheme, the receiver correlates the received signal sequence with the pilot symbol sequence, and obtains the channel estimate [3].

A new channel estimation algorithm for OFDM system based on m-sequence was designed [4]. The m-sequence with Cyclic Prefix (CP) was inserted between OFDM symbols in time domain as a training sequence. The cross-correlation was calculated between the received sequence with CP removed and the appointed circular shifted m-sequence, which takes reliability of the estimation of channel impulse response on account of the two-valued auto-correlation property of the m-sequence, thereby the channel frequency response can be advisably decided [4].

In [5], a pilot sequence design and associated time-domain (TD) MMSE channel estimation algorithm for OFDM system are presented. The investigated method eliminates the use of discreet Fourier transform DFT/IDFT operation before the estimation process, resulting in an undemanding structure with very low computational load [5].

The channel estimation techniques for OFDM system based on pilot-aided were investigated in[6]. A full review of block-type and comb-type pilot based channel estimation was presented. In the block-type pilot arrangement, two simplified estimators based LS and MMSE were presented. They got the conclusion that the Simplified-MMSE and Simplified-LS channel estimator provide practical channel estimation for OFDM system. In the comb-type pilot arrangement, channel estimation was presented by giving the channel estimation methods at the pilot frequencies and the interpolation of the channel at data frequencies [6].

In this work, superimposed pilot channel estimation frame format with the proposed pilot assisted channel estimation (form(3) and form(1) frame formats) are presented in section II, section III, OFDM system based on pilot channel estimation is illustrated. Channel estimation algorithms based on block type are presented in section IV. Section V, contains the simulation results. Finally, conclusion is presented in section VI.

II. Pilot Channel Estimation Frame Formats

Block type pilot channel estimation, has been developed under the assumption of slow fading channel, this assumes that the channel transfer function is not changing very rapidly. The channel estimation can be performed by either inserting pilot tones into all of the subcarriers of OFDM symbols with a specific period or inserting pilot tones into each OFDM symbol.

The system with the superimposed channel estimation has a high spectral efficiency because of the simultaneous transmission of the pilot symbol sequence and the data symbol sequence [3].Figure (1) shows the frame format for superimposed pilot channel estimation. The use of the longer frame, that is, the use of the longer pilot sequence results in the lower correlation between the pilot symbol sequence and the data symbol sequence. However, the use of the longer frame also results in the lower channel tracking capability [3].

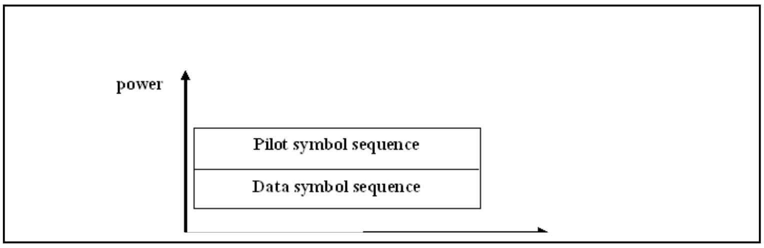


Fig. (1) A frame for superimposed pilot channel estimation

In this work, a random superimposed pilot channel estimation scheme is used, where a pilot sequence is assigned to the transmitter for each frame. Each frame contains 128 pilot symbols superimposed with 128 data symbols.

In the conventional pilot assisted channel estimation, if N is the total number of subchannels, Q is the pilot interval, then P_i =N/Q is the total number of pilots and N-P_i is the total number of data subchannels. Figure (2) shows the arrangement of pilots in conventional pilot assisted channel estimation with N = 256, Q = 8, P_i = 32 and N-P_i = 224.

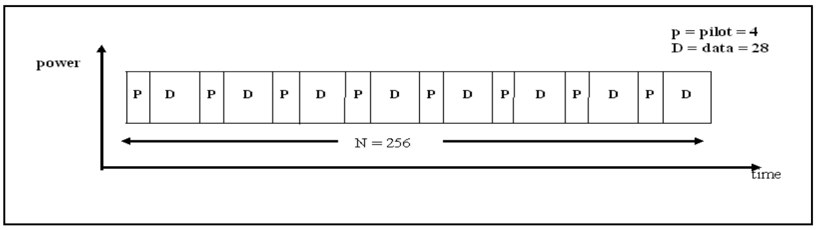
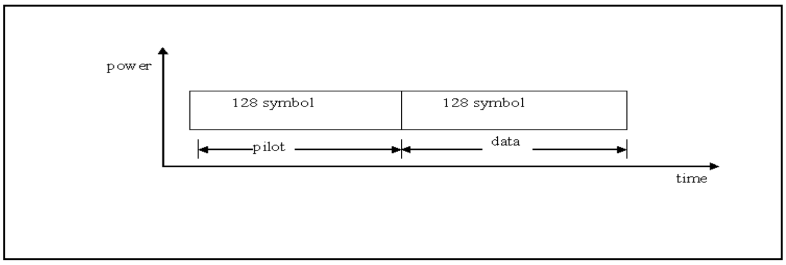
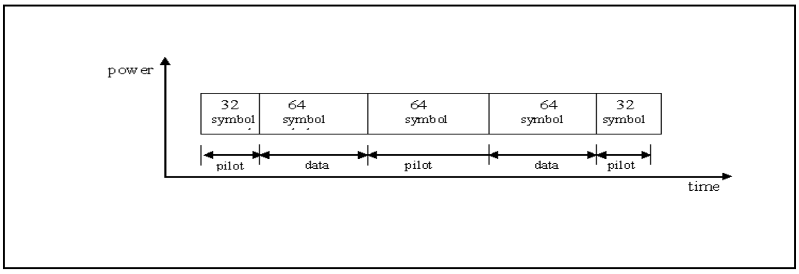


Fig. (2) A frame of conventional pilot assisted channel estimation with N = 256, Q = 8, P_i = 32 and N – P_i = 224.

Also in this work, two frame formats are proposed for pilot assisted channel estimation. The first frame format is called pilot assisted form1 because 128 pilot symbols are inserted at the beginning of the frame. The second frame format is called pilot assisted form3 because 32 pilot symbols are inserted at the beginning, 64 pilot symbols are inserted at the middle and 32 pilot symbols are inserted at the end of the frame. Figure (3) shows the two proposed frame formats for pilot assisted channel estimation.



(a)



(b)

Fig. (3) Proposed two frame formats for pilot assisted channel estimation

a) Pilot assisted form (1)
b) Pilot assisted form (3)

III. System Description

The OFDM system based on pilot channel estimation is shown in Fig. (4) [1]. the binary information is first grouped and mapped according to the modulation in "signal mapper." After inserting pilots either to all sub-carriers with a specific period or uniformly between the information data sequence, IFFT block is used to transform the data sequence of length N{X(*k)*} into time domain signal{*x(n*)} with the following equation [1]:

$$x(n) = \mathit{IFFT}\ \{X(k)\} \qquad n = 0, 1, 2 \ldots, N-1$$
$$= \sum_{k=0}^{N-1} X(k) e^{j(2\pi kn/N)} \qquad (1)$$

Where N is the FFT length. Following IFFT block, guard time, which is chosen to be larger than the expected delay spread, is inserted to prevent inter-symbol interference. This guard time includes the cyclically extended part of OFDM symbol in order to eliminate inter-carrier interference (ICI). The resultant OFDM symbol is given as follows:

$$x_f(n) = \begin{cases} x(N+n), & n = -N_g, -N_g+1, \ldots\ldots, -1 \\ x(n), & n = 0,1,\ldots\ldots, N-1 \end{cases} \qquad \ldots (2)$$

where N_g is the length of the guard interval. The transmitted signal $x_f(n)$ will pass through 3-paths frequency selective Rayleigh fading channel [7]. The channel is modeled using Jacke's model [8]. After adding additive white Gaussian noise (AWGN), the received signal is given by [1]:

$$y_f(n) = x_f(n) \otimes h(n) + n(n) \qquad \ldots (3)$$

Where $n(n)$ is additive white Gaussian noise and $h(n)$ is the channel impulse response. The channel response *h(n)* can be represented by [1]:

$$h(n) = \sum_{k=1}^{K} a_k \sin c\left[\frac{\tau_k}{T_{samp}} - n\right], \qquad -N_1 \leq n \leq N_2 \qquad \ldots (4)$$

Where,

- T_{Samp} Is the input sample period to the channel.
- τ_k, where $1 \leq \kappa \leq k$, is the set of path delays. K is the total number of paths in the multipath fading channel.
- $\{a_k\}$, where $1 \leq \kappa \leq k$, is the set of complex path gains of the multipath fading channel. These path gains are uncorrelated with each other.
- N_1 and N_2 are chosen so that $h(n)$ is small when n is less than N_1 or greater than N_2.

At the receiver, the guard time is removed:

$$\begin{aligned} &y_f(n) \quad for - N_g \leq n \leq N-1 \\ &y(n) = y_f(n+N_g) \qquad n = 0,1,\ldots\ldots, N-1 \end{aligned} \qquad \ldots (5)$$

Then *y(n)* is sent to FFT block for the following operation:

$$\begin{aligned} Y(k) &= FFT\{y(n)\} \qquad k = 0,1,2,\ldots\ldots, N-1 \\ &= \frac{1}{N}\sum_{n=0}^{N-1} y(n) e^{-j(2\pi k n/N)} \end{aligned} \qquad \ldots (6)$$

Following FFT block, the pilot signals are extracted and the estimated Channel $\hat{H}$ for the data sub-channels is obtained in channel estimation block using either LS estimator or MMSE estimator. Then, the transmitted data is estimated by [1]:

$$\hat{X} = \frac{Y(k)}{\hat{H}(k)} \quad , k = 0,1,......, N-1 \qquad \dots (7)$$

Finally, the binary information data is obtained back in demodulator and signal demapper block.

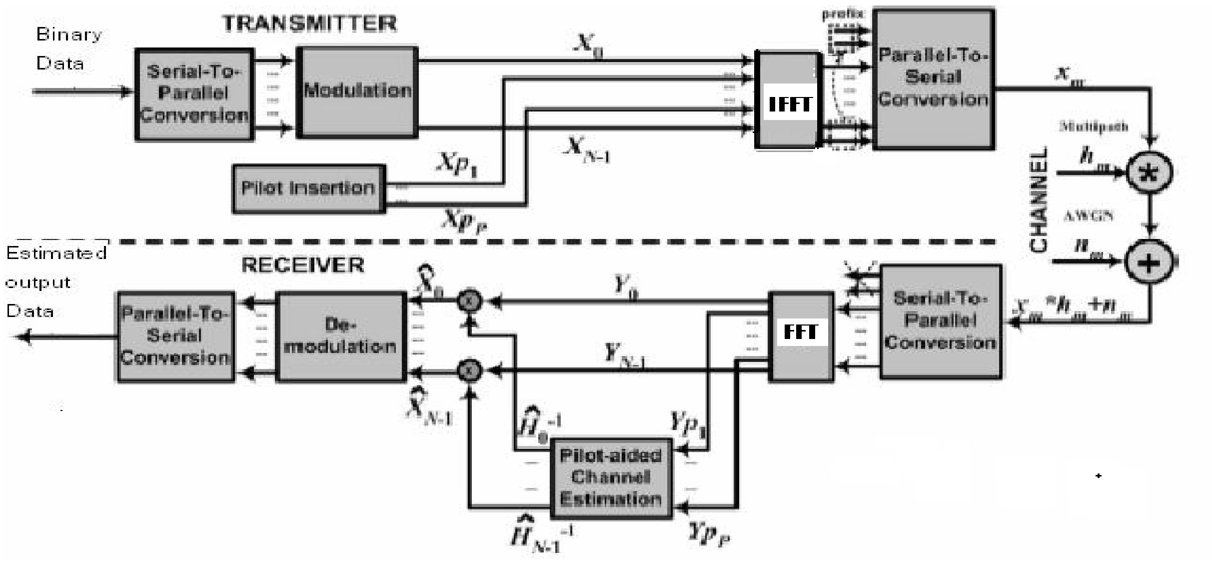


Fig. (4) OFDM system based pilot channel estimation

IV. Channel Estimation Based On Block-Type Pilot Arrangement

In block-type pilot-based channel estimation, OFDM channel estimation symbols are transmitted periodically, and all subcarriers are used as pilots. The task here is to estimate the channel conditions (specified by H or h) given the pilot signals (specified by X) and received signals (specified by Y), with or without using certain knowledge of the channel statistics. The receiver uses the estimated channel conditions to decode the received data inside the block until the next pilot symbol arrives. The estimation can be based on least square (LS) and minimum mean-square error (MMSE) estimators [9, 10].

A. Least Square (LS) Estimation

The idea behind least squares is to fit a model to measurements in such a way that weighted errors between the measurements and the model are minimized [5]. The LS estimates H, given the received data Y and the transmitted symbols X is given by [9, 10]:

$$\hat{H}_{LS} = X^{-1} Y \qquad (k = 0,......, N-1) \qquad \dots (7)$$

without using any knowledge of the statistics of the channels [10], the LS estimators are calculated with very low complexity, but they suffer from a high mean-square error [10,11, 12].

The main advantage of this estimator is its simplicity: one division per carrier. The main disadvantage is its poor performance, due to the use of an oversimplified channel model. Indeed, the frequency and time correlation of the channel are not taken into account in the LS estimator [12].

B. Minimum Mean – square Error (MMSE) Estimator

The MMSE estimator employs the second-order statistics of the channel conditions to minimize the mean-square error. Denote by R_{hh}, R_{HH} and R_{YY} the auto covariance matrix of h, H and, Y respectively, and by R_{hY} the cross covariance matrix between h and Y. Also denote by σ^2 the noise variance. Assume the channel vector and the noise are uncorrelated, it is derived that [10, 11, 13]:

$$R_{HH} = E\{HH^H\} = E\{(Fh)(Fh)^H\} = FR_{hh}F^H \quad \ldots (8)$$

$$R_{hY} = E\{hY^H\} = E\{h(XFh + N)\} = R_{hh}F^H X^H \quad \ldots (9)$$

$$R_{YY} = E\{YY^H\} = XFR_{hh}F^H X^H + \sigma^2 I \quad \ldots (10)$$

The FFT matrix F is given by [14]:-

$$F = \begin{bmatrix} W_N^{00} & \cdots & W_N^{0(N-1)} \\ & \ddots & \\ W_N^{(N-1)0} & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix} \quad \ldots (11)$$

Where $W^{i,k} = (1/\sqrt{N})^{-j2\pi(ik/N)}$

Assume R_{hh} (thus R_{HH}) and σ^2 are known at the receiver in advance, the MMSE estimator of h is given by

[10, 12]

$$\hat{h}_{MMSE} = R_{hY} R_{YY}^{-1} Y_{HH} \quad \ldots (12)$$

Note that if h is not Gaussian, $\hat{h}_{MMSE}$ is not necessarily a minimum mean-square error estimator, but it is still the best linear estimator in the mean-square error sense. At last, it is calculated that

$$\hat{H}_{MMSE} = F\hat{h}_{MMSE} \; F\left[(F^H X^H)^{-1} R_{hh}^{-1} \sigma^2 + XF\right]^{-1} Y \quad \ldots (13)$$

$$= FR_{hh}\left[(F^H X^H XF)^{-1} \sigma^2 + R_{hh}\right] F^{-1} \hat{H}_{LS} \quad \ldots (14)$$

$$= R_{HH}\left[R_{HH} + \sigma^2\left(XX^H\right)^{-1}\right]^{-1}\hat{H}_{LS} \qquad \ldots (15)$$

The MMSE estimator yields much better performance than LS estimators, especially under the low SNR scenarios. A major drawback of the MMSE estimator is its high computational complexity, especially if matrix inversions are needed each time the data in X changes [10]

V. Simulation Results

The simulation parameters are listed in Table (I):

Table (I) Simulation Parameters

<table>
<tr><td rowspan="4">Transmitter</td><td>Data modulation</td><td>QPSK</td></tr>
<tr><td>Number of IFFT points</td><td>128</td></tr>
<tr><td>Guard interval</td><td>32</td></tr>
<tr><td>Pilot arrangement types</td><td>Superimposed, pilot aided form(3) &pilot aided form(1)</td></tr>
<tr><td>Channel</td><td colspan="2">3. paths frequency selective Rayleigh fading channel Model of the channel: Jake’s model</td></tr>
<tr><td rowspan="2">Receiver</td><td>Number of FFT points</td><td>128</td></tr>
<tr><td>Channel Estimation</td><td>MMSE & LS</td></tr>
</table>

This simulation deals with the bit error rate (BER) performance of OFDM system in 3-paths frequency selective Rayleigh fading channel.

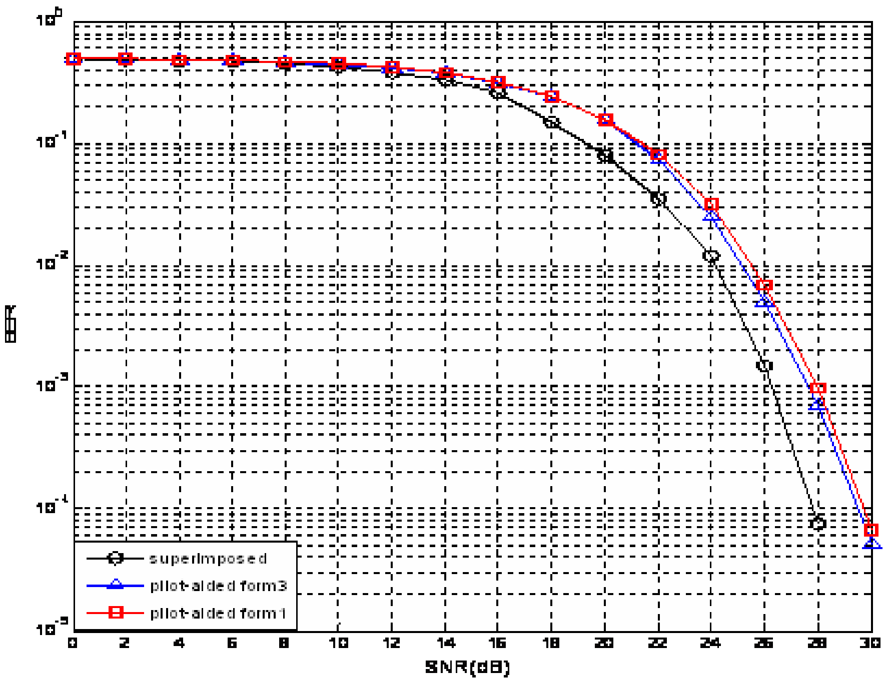


Fig. (5) BER Performance Of OFDM System Based LS Estimator For Three Types Of Pilot Arrangement In Flat Rayleigh Fading Channel

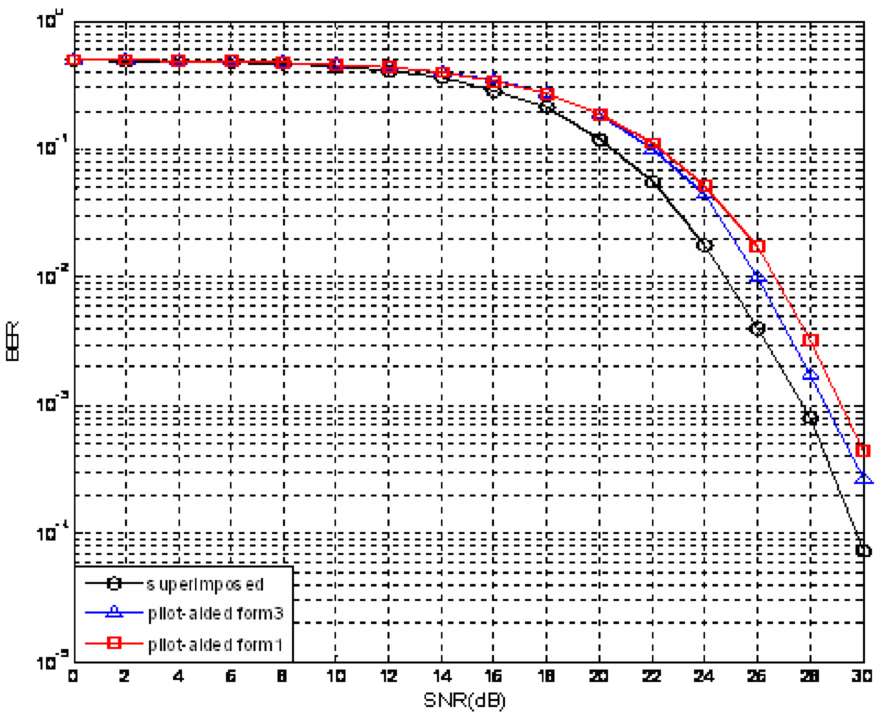


Fig. (6) BER performance of OFDM system based LS estimator for three types of pilot arrangement in 2paths Rayleigh fading channel

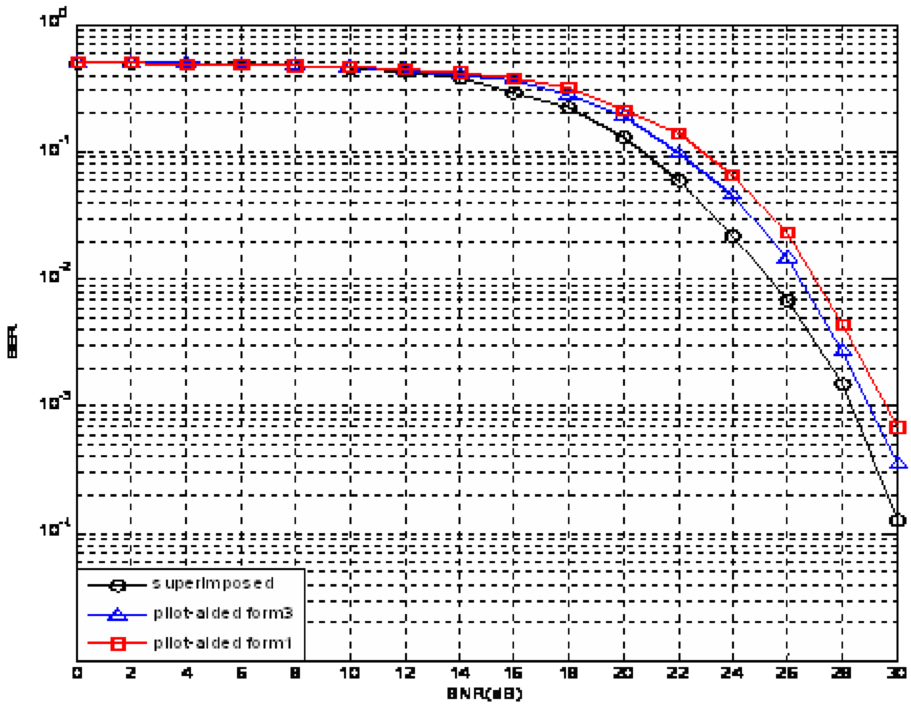


Fig. (7) BER performance of OFDM system based LS estimator for three types of pilot arrangement in 3paths Rayleigh fading channel

Figures (5),(6)and (7) show a comparison in BER performance versus SNR values between three schemes (superimposed,pilot-aided form(3)and pilot-aided form(1)) of pilot arrangement in flat, 2-paths and 3-paths frequancy selective Rayleigh fading channel .The estimation is based on LS with Doppler frequency (f_D) is 30Hz, $T_m = T_s$, where T_m is the multipath delay spread and T_s is the symbol period. The three schemes of pilot arrangement give almost the same bit error rate at low SNR values, because the noise level is very high. Table (II) lists the gain in (dB),obtained at BER=10^{-3} ,by comparing pilot-aided form(3) and pilot-aided form(1) with superimposed pilot scheme based LS estimator in flat, 2-paths and 3-paths frequency selective Rayleigh fading channel.

Table (II) Gain (Db) Obtained By Comparing Pilot Arrangement Schemes Based LS Estimator At BER = 10^{-3}

No. Of Paths	**Gain(Db) Superimposed & Pilot-Aided Form (3)**	**Gain(Db) Superimposed & Pilot-Aided Form (1)**
Flat	1.4	1.7
2-Paths	1.1	1.4
3-Paths	0.8	1.2

From this table, it can be noticed that the BER performance of superimposed pilot scheme outperforms the other two schemes in flat, 2-paths and 3-paths frequency selective Rayleigh fading channel.

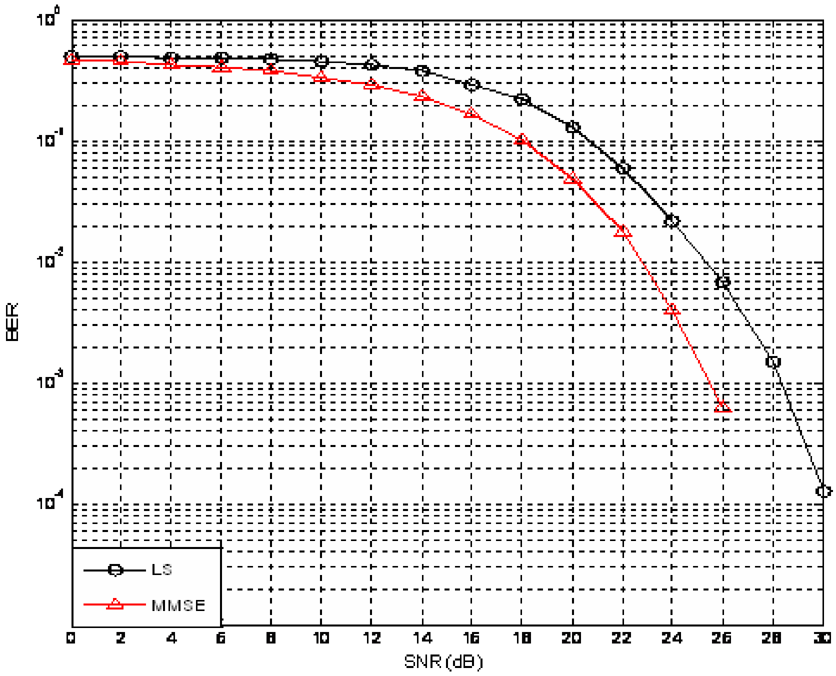


Fig. (8) BER performance of OFDM system based LS & MMSE estimators using superimposed pilot arrangement in 3-paths Rayleigh fading channel

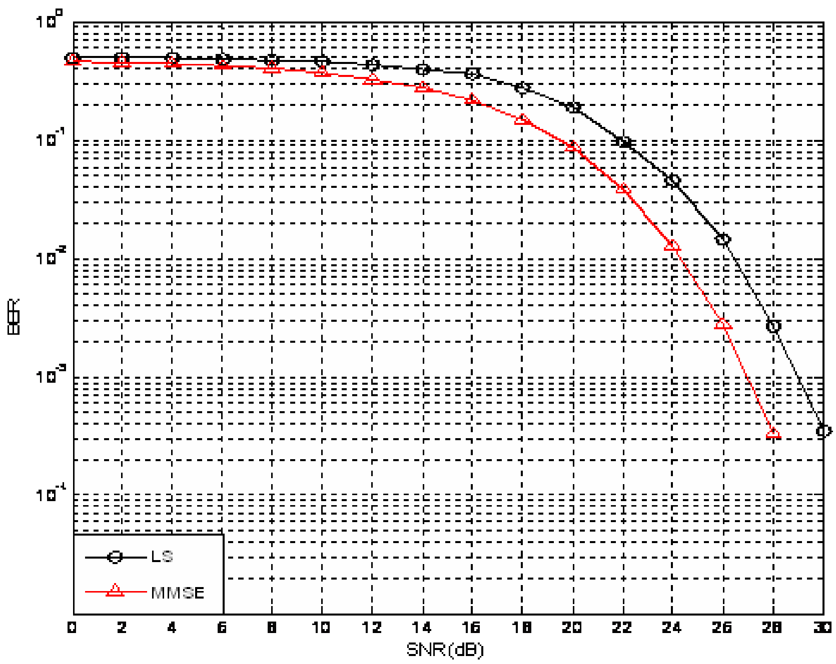


Fig. (9) BER performance of OFDM system based LS &MMSE estimators for pilot-aided form3 arrangement in 3-paths Rayleigh fading channel

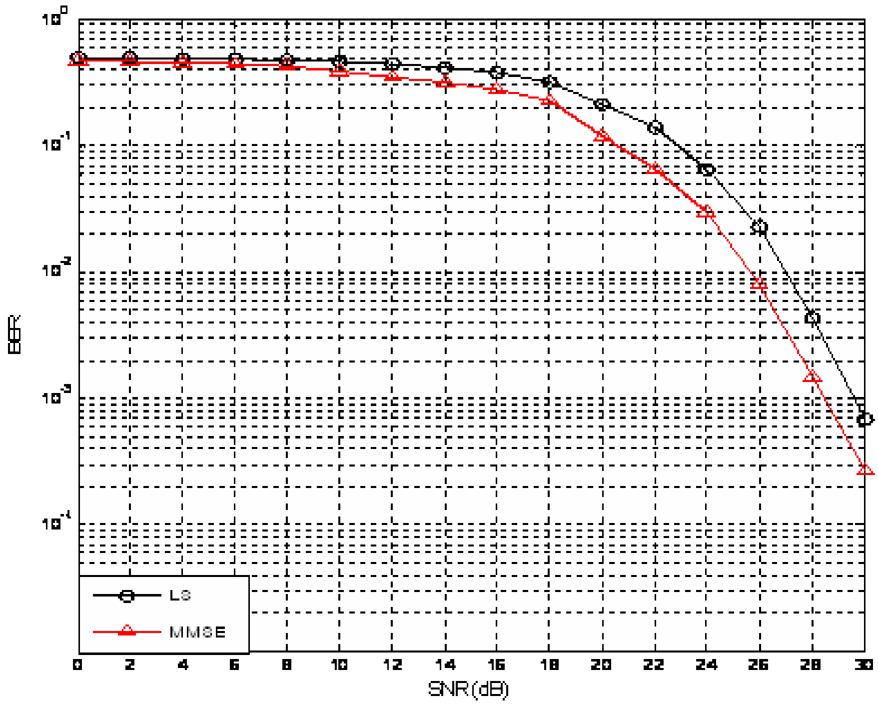


Fig. (10) BER performance of OFDM system based LS &MMSE estimators for pilot-aided form(1) arrangement in 3-paths Rayleigh fading channel

Figures (8),(9)and (10) show a comparison in BER performances versus SNR values between LS estimator and MMSE estimator in 3-paths Rayleigh fading channel with all types of pilot arrangement, using f_D = 30Hz, N_c = 128 and $T_m = T_s$.

For slowly varying channels, i.e., f_D at 30Hz, the BER performance, at SNR=18 dB for superimposed pilot arrangement based LS estimator, is better for all values of Doppler frequency than other forms of pilot arrangements, as shown in Fig.(11). V

Figure (12) shows a BER performance comparison between LS and MMSE estimators for superimposed pilot arrangement at SNR=18dB with Doppler frequencies range (30 – 150) Hz. From this figure, it is clear that, low BER values are obtained at low f_D values and MMSE estimator performs much better than LS estimator [16].

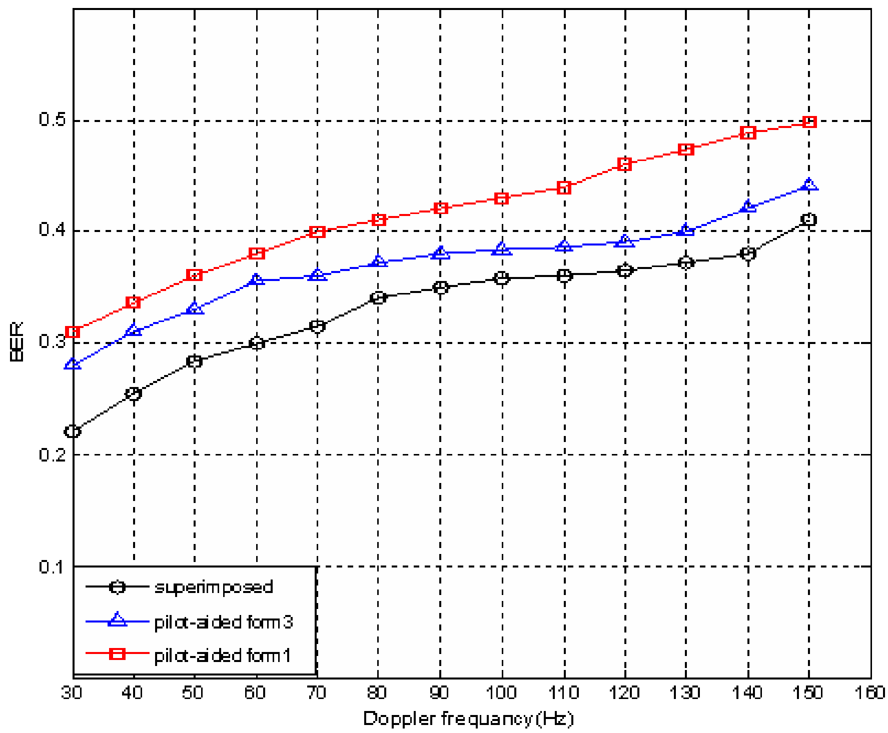


Fig. (11) BER performance of OFDM system based LS estimator for all forms of pilot arrangement at SNR=18dB with Doppler frequancies range (30 – 150) Hz in 3-paths Rayleigh fading channel

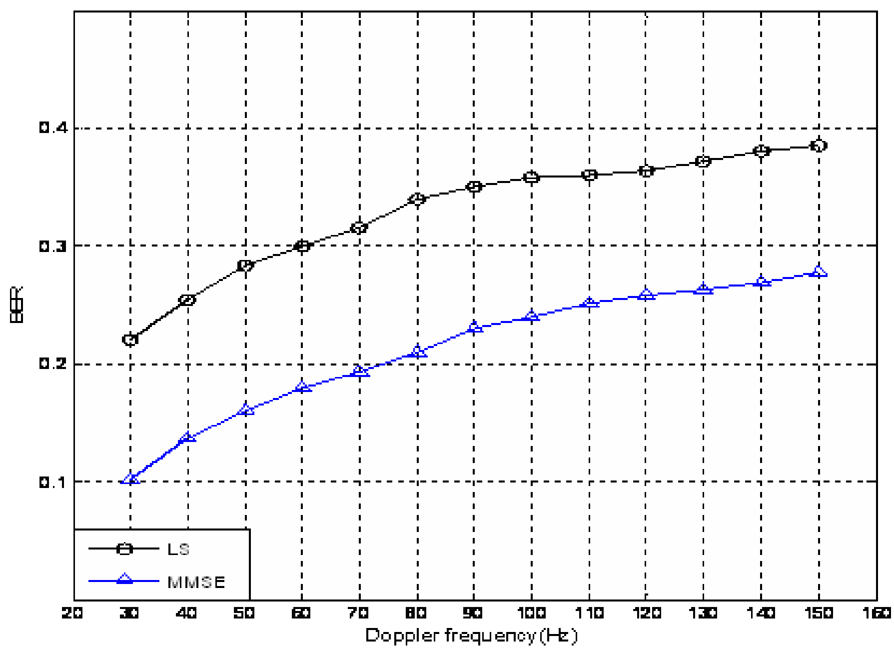


Fig. (12) BER performance of OFDM system based LS and MMSE estimators with superimposed pilot arrangement at SNR=18dB and Doppler frequancies range(30 – 150)Hz in 3-paths Rayleigh fading channel

The BER performance versus SNR values of OFDM system based LS and MMSE estimators with variable multipath time delays in three paths Rayleigh fading channel are illustrated in Figs.(13), (14), and (15) using LS estimator and Figs. (16), (17) and (18) for MMSE estimator respectively.

The Doppler frequency is 30 Hz and N_C= 128. The variable multipath time delays chosen are $T_m = T_s /2$, $T_m = T_s$ and $T_m = 2 * T_s$.

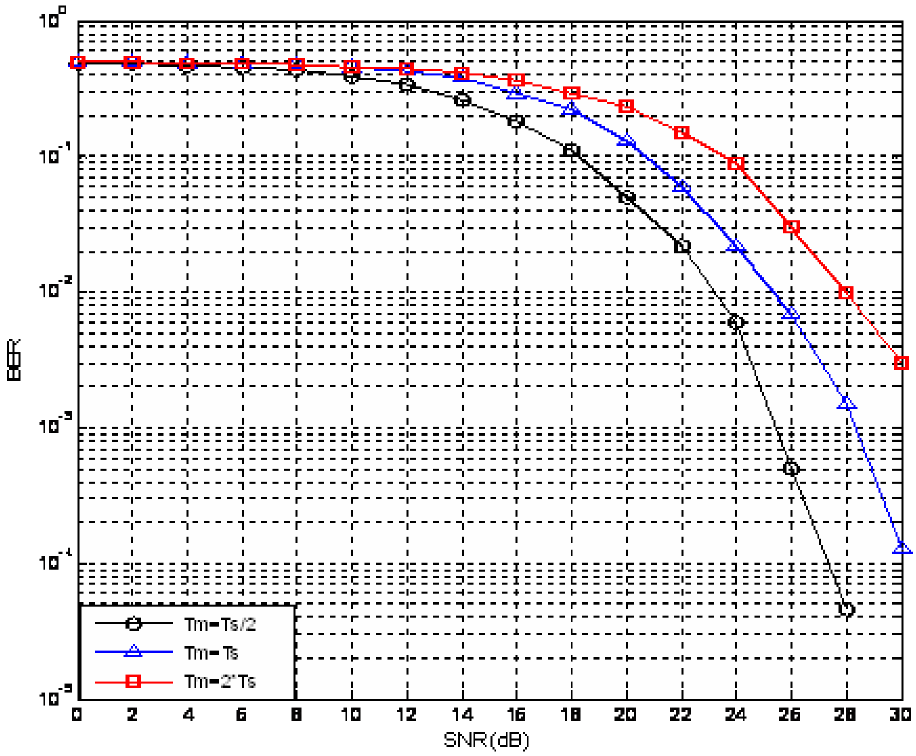


Fig. (13) BER performance of OFDM system based LS estimator with superimposed pilot arrangement and variable time delays in 3-paths Rayleigh fading channel

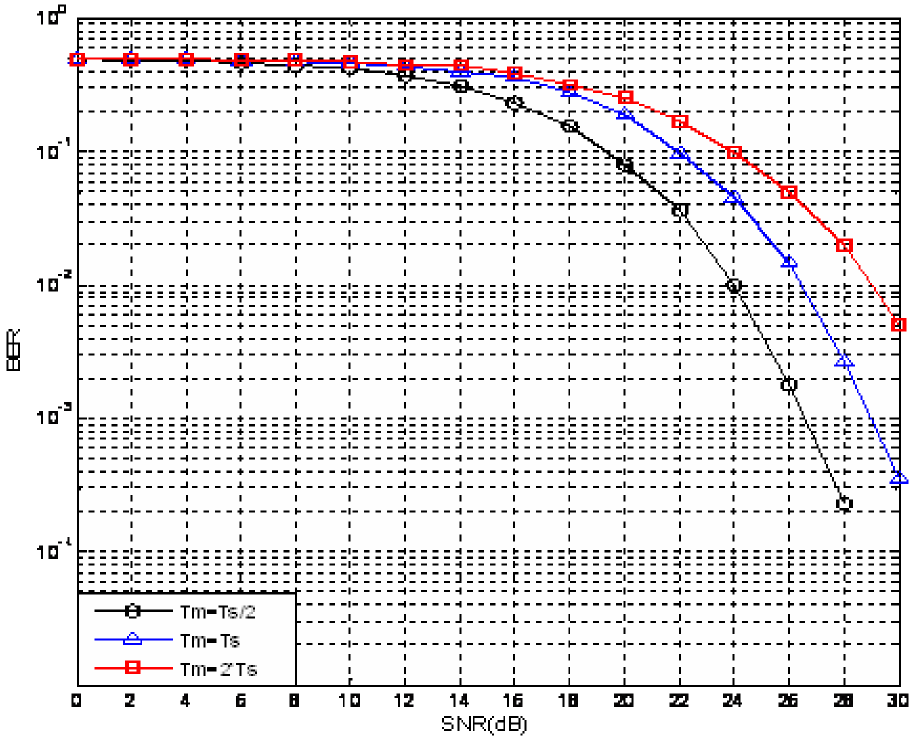


Fig. (14) BER performance of OFDM system based LS estimator with pilot-aided form3 arrangement and variable time delays in 3-paths Rayleigh fading channel

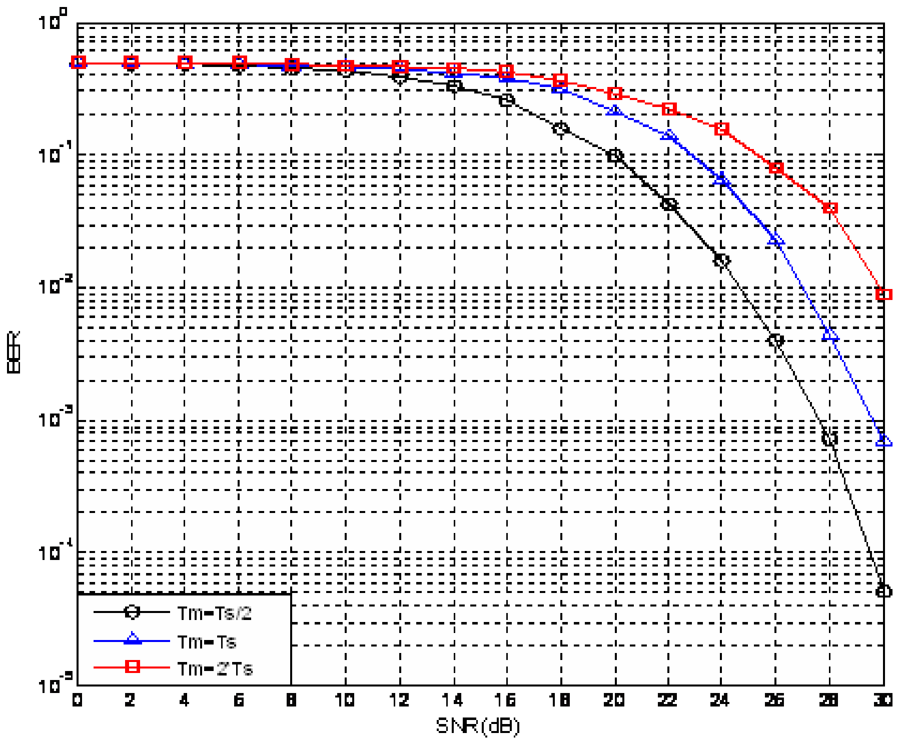


Fig. (15) BER performance of OFDM system based LS estimator with pilot-aided form1 arrangement and variable time delays in 3-paths Rayleigh fading channel

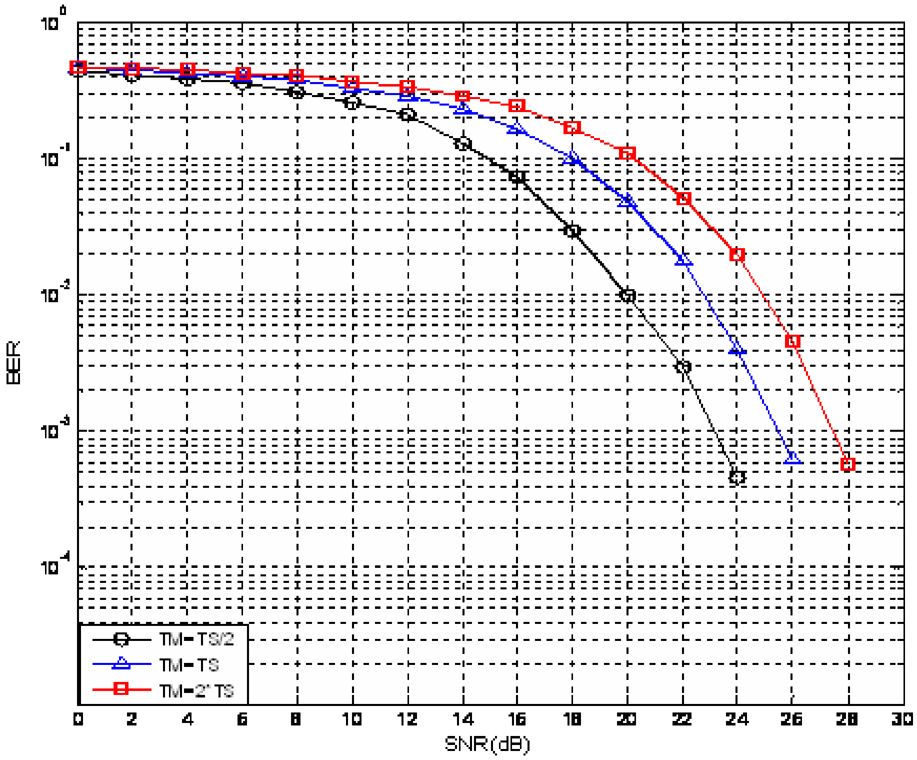


Fig. (16) BER performance of OFDM system based MMSE estimator with superimposed pilot arrangement and variable time delays in 3-paths Rayleigh fading channel

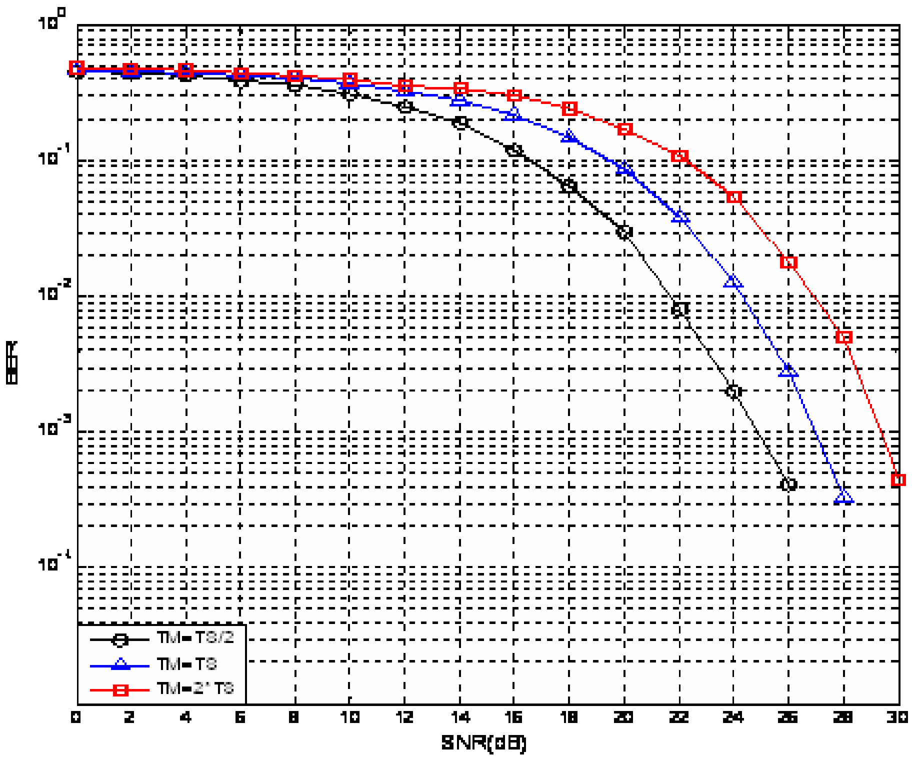


Fig. (17) BER performance of OFDM system based MMSE estimator with pilot -aided form3 arrangement and variable time delays in 3-paths Rayleigh fading channel

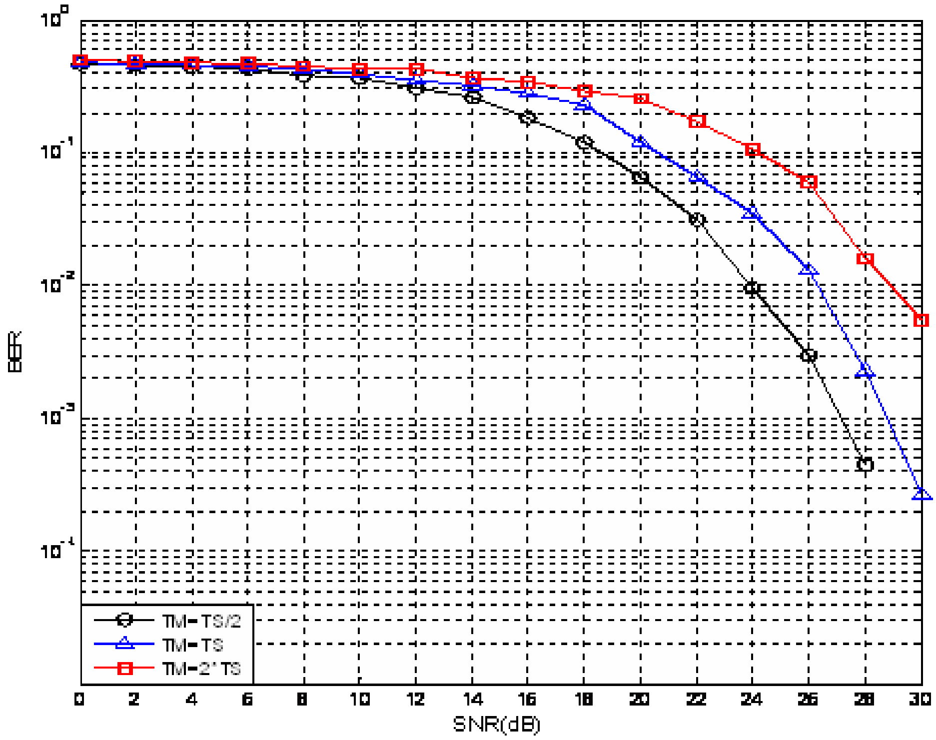


Fig. (18) BER performance of OFDM system based MMSE estimator with pilot -aided form1 arrangement and variable time delays in 3-paths Rayleigh fading channel

For a delay spread that is longer than the effective guard period, the BER rises rapidly due to the inter-symbol interference. The maximum BER occurs when the delay spread is very long (≥the symbol time) as this will result in strong inter-symbol interference [15].

The MMSE estimator still achieves better BER performance, as compared with LS estimator for all types of pilot arrangement, and still superimposed pilot arrangement scheme is the best scheme for obtaining a good BER performance among the other forms.

V. Conclusion

The simulation shows the comparison between three different pilot schemes in different paths of Rayleigh fading channel. When the number of paths increases, the ISI increases and the BER performance gets worse. The BER performance of superimposed pilot scheme performs better than pilot-aided form (3) and pilot-aided form (1) in flat, 2-paths and 3-paths frequency selective Rayleigh fading channel. This is because in superimposed channel estimation, the data and the training pilots are transmitted together, pilot sequence is chosen with low correlation with data symbol sequence and the frequency response of the channel can be estimated with low BER.

Hence the performance is better than that with pilot-aided schemes but on the expense of high spectral efficiency of the superimposed channel estimator. Pilot-aided form (3) performs better than pilot-aided form (1) because its pilots have the ability to track the channel in more efficient way than pilot-aided form (1).

From the comparison in BER performances versus SNR values between LS estimator and MMSE estimator in 3-paths Rayleigh fading channel with all types of pilot arrangement, it can be concluded that, the MMSE estimator achieves better BER performance, as compared with LS estimator for all types of pilot arrangement.

The conclusion from the comparison in block type channel estimation for different values of Doppler frequency based LS and MMSE estimators is that the block type channel estimation has good performance if channel is changed very slowly. This is an expected result, because at higher Doppler frequencies, channel transfer function changes so fast that there are even changes for adjacent OFDM symbol (ICI caused by Doppler shifts).

From the simulation, it is clear that, for a delay spread longer than the effective guard period, the BER rises rapidly due to the inter-symbol interference.

References

1. S. Coleri, M. Ergen, A. Puri, and A. Bahai , "Channel Estimation Techniques Based on Pilot Arrangement in OFDM Systems", IEEE Transaction on Broadcasting ,vol.48, No.3, September 2002, pp.223- 229.

2. J.J. V. de Beek, O. Edfors, M. Sandell, S. K. Wilson and P. O. Borjesson," On Channel Estimation in OFDM Systems", IEEE Communications Magazine,Vol.33, No.7, pp. 815 -819, June 1995.

3. F. Tsuzuki and T. Ohtsuki," Channel Estimation with Selective Superimposed Pilot Sequences under Fast Fading Environments", Dept. of Electrical and Engineering, Tokyo University of Science, IEEE Globecom, Vol.149, No.20, pp. 240-246, 2004.

4. G. Xu, Q. Wei, X. Zhang, and D. Yang," New OFDM Channel Estimation Algorithm with Low Complexity", Wireless Theories and Technologies(WT&T), Beijing University of Posts and Telecommunications, IEEE Transactions on signal processing, Vol.55,No.5 ,pp. 2257-2260, 2007.

5. C. Ribeiro," An OFDM Symbol Design for Reduced Complexity MMSE Channel Estimation", Journal of Communication, Vol. 3, No. 4, pp 26-33, September 2008.

6. H. Chunlong and H. Li," Pilot-Aided Channel Estimation Techniques OFDM System", International Conference on Communication Software and Networks, IEEE Computer Society(iccsn), pp.143-146, 2009.

7. X. Wu, G. Kang, T. Tang, P. Zhang, and M. Zhou, "An Pilot Assisted Channel Estimation Method for OFDM Systems in Time Varying Channels", Wireless Technology Innovation Institute, Beijing University of Posts and Telecommunications, China, The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'07), IEEE , 2007.

8. W. Wu, V. V. G. Srinivasan, C. Hsu, Y. Kim and C. Lee," Optimal Channel Estimation for Capacity Maximization in OFDM Systems", Wireless Communication Project (EE381K-11) Technical Report, Dept. of Electrical and Computer Engineering, The University of Texas at Austin, Austin, TX, May 6, 2003, http://www.ece.utexas.edu/.

9. K. Arshad," Channel Estimation in OFDM System", M.Sc thesis, Dept.of Electrical Engineering, College of Engineering, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, August 2002.

10. Y. Shen and E. Martinez,"Channel Estimation in OFDM System", Freescale Semiconductor, www.freescale.com , 2006.

11. M. Morelli and U. Mengali,"A Comparison of Pilot-Aided Channel Estimation Methods for OFDM Systems", IEEE Transactions on Signal Processing, Vol. 49, No. 12, pp. 3065-3073, December 2001.

12. E. Golovins, and N. Ventura, ”Comparative Analysis of Low Complexity Channel Estimation Techniques for the Pilot-assisted Wireless OFDM Systems", IEEE Intern. Conf. Commun. (ICC), pp. 1640-1645, April 2005.

13. R. Tesi, M. Hämäläinen and J. Iinatti,"Channel Estimation Algorithms Comparison for Multiband OFDM", the 17th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'06), pp.1-5, 2006.

14. M. I. Rahman, S. S. Das, and F.H.P. Fitzek," OFDM Based WLAN Systems", Technical Report, Center for TeleInFrastruktur (CTiF), JADE project Deliverable, Aalborg University, Denmark, 18 February 2005.

15. E. Lawrey," The suitability of OFDM as a modulation technique for wireless telecommunications, with a CDMA comparison", Dept. of Electrical Engineering and Computer Science, James Cook University, October 1997, www.eng.jcu.edu.au/eric.htm .

16. F .N.Al-Nuaimy,"Performance of channel estimation for (OFDM) system based on block – type pilot arrangement in Rayleigh fading channel ", M.Sc thesis, Dept.of Electrical Engineering, College of Engineering, Al- Mustansiriya University, 2010.