ISSN 2047-3338

Evaluation of Kalman Filtering Based Channel Estimation for LTE-Advanced

Saqib Saleem and Qamar-ul-Islam

***Abstract*– For high data rate multimedia services and growing demand of wireless internet, in 2007 ITU invited proposals for 4th Next Generation Communication systems, for which 3GPP proposed LTE-A, based on Rel-10, fulfilling the requirements of IMT-A. In this paper extension of two linear frequency-domain channel estimation techniques, LSE and LMMSE are analyzed by using Kalman Filtering Algorithm. The performance of LMMSE-Kalman is better than LSE-Kalman as first one uses the second order noise and channel statistics. Two channel parameters are used for analysis, channel filter length, in terms of Channel Impulse Response (CIR) samples and multi-path channel taps. MATLAB Monte Carlo Simulations are performed to make performance and complexity comparison of these two methods. The performance is evaluated in terms of Mean Square Error (MSE) and complexity shows the computational time taken by the channel estimator for different MIMO systems.**

***Index Terms*– LSE, LMMSE, DFT, DCT, Windowed-DFT, LTE and MIMO-OFDM**

I. INTRODUCTION

FOR next generation broadband wireless communication systems, 3GPP proposed Rel-10 based LTE-Advanced system, whose performance capabilities are extensions of previously Rel-8/9 based LTE system, with the following new features [1]:

Carrier aggregation, co-ordinated multi point transmission and reception (CoMP) with support of multiple antennas, co-operative communication using relaying nodes and heterogeneous networking. These enhancements make LTE-A system comparable to IMT-A, for example in IMT-A minimum supported bandwidth required is 40 MHz but in LTE-A, up to 100MHz transmission bandwidth can be achieved through carrier aggregation. Spectral efficiency of LTE-A is 30 b/s/Hz for DL case and 16.6 b/s/Hz for 8×8 UL MIMO system while in IMT-A the targeted values are: 15b/s/Hz for DL and 6.75 b/s/Hz for UL. Latency requirement of IMT-A should be less than 100 ms for control plane but in LTE-A, less than 50 ms are required [2].

To achieve the high data rate and spectral efficiency, the implementation of adaptive modulation and coding (AMC), open loop and closed loop power control, requires channel knowledge at both ends of a transceiver. For channel estimation, either reference signals can be transmitted along with the data or received data bearing only information can be used. The first one scheme is called non-blind channel estimation which gives reduced spectral efficiency while second technique is called blind channel estimation which is not suitable for high mobility situations where the channel is facing fast fading.

Channel can be estimated either in frequency domain or in time domain. Least Square Error (LSE) and Linear Minimum Mean Square Error (LMMSE) are two linear channel estimation techniques [3] which rely on time-domain behavior of channel statistics. In frequency-domain channel can be estimated by DFT-CE, DCT-CE or Windowed-DFT CE [4]. Under fast varying environmental conditions adaptive filters can be used for tracking and estimating the channel. Linear channel estimation techniques can be extended by using Kalman Filter as channel estimator. LMMSE-Kalman estimator has better performance than LSE-Kalman but it has more complexity as LMMSE exploits second order channel statistics. Under fast fading noise channels, the performance can be optimized by taking appropriate length of channel filter and number of multi-path channel taps. Both these parameters are used for performance and complexity evaluation of both LSE-Kalman and LMMSE-Kalman estimators for different MIMO systems [5].

The rest of the paper is organized as: Section II gives details of MIMO-OFDM system model, in Section III Kalman Filtering algorithm is discussed which is used as channel estimator and simulation results are given in next section. Last section draws conclusion along with future work proposed.

II. SYSTEM MODEL

The impulse response of a wireless channel is given by [6].

$$h(t,\tau) = \sum_i \gamma_i(t) p(\tau - \tau_i) \qquad (1)$$

Saqib Saleem is with Department of Communication System Engineering at Institute of Space Technology, Islamabad, Pakistan. He is currently a student of MS Communication Engineering. His areas of interest are Channel Estimation, Wireless Communication, DSP algorithms.

Dr. Qamar-ul-Islam is with Department of Communication System Engineering at Institute of Space Technology, Islamabad, Pakistan. He is currently Head of Department His areas of interest are Estimation and Detection Theory, Wireless Communication and Satellite Communication.

Where τ_i shows the delay for the signal of i^{th} path in case of multi-path channel, γ_i is the complex gain of the channel which is a wide-sense stationary (WSS) Gaussian process. t denotes that the channel behavior is changing with time. The power delay profiles for all channel paths for MIMO system are considered as having same delay profile.

After passing through such channel, the received signal at time t is given by [6]

$$y_r(t) = \sum_{r=0}^{K-1} \sum_{t=1}^{M_T} h_{i,r}^{k}(t) x_i(t-k) + n_r(t) \qquad (2)$$

Where K shows the total number of multi-path channel taps and M_T is number of transmit antennas. $h_{i,r}^{k}$ is the gain of the k^{th} channel tap for i^{th} transmit antenna and r^{th} receive antenna.

Transceiver structure of MIMO-OFDM system is shown in Figure 1. According to this system model, at a time two blocks of data are taken and are passed through two space-time block encoders. After encoding the data symbols, IFFT is applied which modulates the k^{th} OFDM symbol on n^{th} carrier frequency. In order to avoid inter-carrier interference (ICI) and inter-symbol interference (ISI), cyclic prefix of suitable length is added. After passing through multipath fast fading channel, the k^{th} received OFDM symbol at n^{th} frequency can be written as for the above described MIMO-OFDM system

$$y_j[n,k] = \sum_{i=1}^{M_T} H_{i,j}[n,k] x_i[n,k] + N_j[n,k] \qquad (3)$$

Where y_j is received signal at j^{th} receive antenna.

The above expression for L space-time encoders can be written in vector-form as [8]

$$\boldsymbol{r}[n,k] = \boldsymbol{H}_1[n,k] x_1[n,k] + \dots + \boldsymbol{H}_L[n,k] x_L[n,k] + \boldsymbol{N}[n,k] \qquad (4)$$

Where, $\boldsymbol{r}[n,k] = \begin{bmatrix} r_1[n,k] \\ \vdots \\ r_{N_R}[n,k] \end{bmatrix}$ $\boldsymbol{N}[n,k] = \begin{bmatrix} n[n,k] \\ \vdots \\ n_{N_R}[n,k] \end{bmatrix}$

$$\boldsymbol{x}_i[n,k] = \begin{bmatrix} x_{N_R i - N_R} \\ \vdots \\ x_{N_R i} \end{bmatrix}$$

And channel matrix is

$$H_i[n,k] = \begin{bmatrix} H_{N_R i - N_R, 1} & H_{N_R i, 1} \\ \vdots & \vdots \\ H_{N_R i - N_R, N_R} & H_{N_R i, N_R} \end{bmatrix}$$

At receiver side, multiples of transmitted signal are received at all antennas. In order to select any one suitable signal, space-time processor is used before decoding the symbols. Channel is required to be estimated both for space-time processor and decoder.

III. KALMAN-FILTERING BASED CHANNEL ESTIMATION

Channel can be estimated by using the following state space vector [9].

$$h_{r,t}[n+1] = F h_{r,t}[n] + v_{r,t}[n] \qquad (5)$$

Where, $h_{r,t}[n] = (h_{r,t_n}[0] \; h_{r,t_n}[1] \; \dots \; h_{r,t_n}[L-1])^T$, F is $M_T \times N_R$ channel matrix showing the state transition of $h_{r,t}[n]$. $v_{r,t}[n]$ is the complex white Gaussian Noise.

At receiver the signal is given by [10].

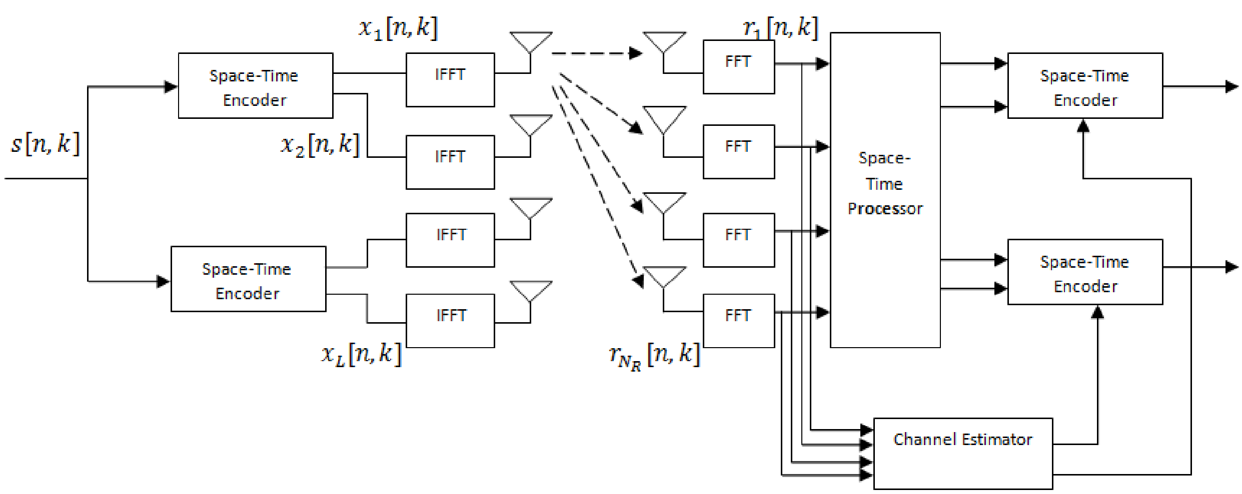

Fig.1: MIMO-OFDM System Model [7]

$$y_{r,t}[n] = {h_{r,t}}^{H}[n]x_{r,t}[n] + w_{o_{r,t}}[n] \qquad (6)$$

The following Kalman Filtering equations are performed iteratively to find the estimated channel [10].

$$\hat{h}_{r,t}[n/n-1] = F\hat{h}_{r,t}[n-1/n-1] \qquad (7)$$

$$e[n/n-1] = y_{r,t}[n] - {\hat{h}_{r,t}}^{H}[n/n-1]x_{r,t}[n] \qquad (8)$$

$$q[n] = \sum_{k=0}^{L-1}[R_{h_{r,t}}[0]]_{k,k}\,\sigma^{2}_{x\,r,t}[n-k] + N_{o_{r,t}} \qquad (9)$$

$$k[n] = \frac{P[n/n-1]x_{r,t}[n]}{q[n] + {x_{r,t}}^{H}[n]P[n/n-1]x_{r,t}[n]} \qquad (10)$$

$$\hat{h}_{r,t}[n/n] = \hat{h}_{r,t}[n-1/n-1] + k[n]e^{*}[n/n-1] \qquad (11)$$

$$P[n+1/n] = F\left(I - k[n]{x_{r,t}}^{H}[n]\right)P[n/n-1]F^{H} + Q_{v_{r,t}}[n] \qquad (12)$$

Initialized parameters are:

$$\hat{h}_{r,t}[-1/-1] = \mu_{h_{r,t}} \qquad (13)$$

$$P[-1/-1] = C_{h_{r,t}} \qquad (14)$$

$k[n]$ is the gain vector of Kalman filter.
$Q_{v_{r,t}}[n]$ is the covariance matrix of the Gaussian noise $v_{r,t}[n]$ and

$$R_{h_{r,t}}[0] = E\left[\hat{h}_{r,t}[n/n-1]{\hat{h}_{r,t}}^{H}[n/n-1]\right] + P[n/n-1] \qquad (15)$$

IV. SIMULATION RESULTS

In this section, the results of Monte-Carlo Simulations are presented for different MIMO systems i.e. 2×2, 3×3 and 4×4 systems with an OFDM system having 64 sub-carriers and BPSK modulation under Rayleigh Fading channel with CP length of 16. Maximum filter length under consideration is takeen of 64 CIR samples and maximum number of channnel taps are also64.

The performance of Kalman Filtering based channel estimator is given in Fig. 2. For low SNR operating conditions, the performance degrades as we increase the channel filter length. Performance remains same for channel length up to 10-15 CIR Samples but after this value the performance goes on degrading. But as we increase SNR value, the effect of CIR samples on performance goes on diminishing and at high SNR value of 5dB, MSE remain almost constant for all channel filter lengths. The performance comparison for different MIMO systems is shown in Fig. 3. We observe that for channel filter length up to 40-45 CIR samples, 2×2 MIMO system outperforms the 4×4 MIMO system but as we increase the lentgh of channel filter further the 4×4 MIMO system gives better performance behavior. So for larger channel filter lengths higher order MIMO systems are preffered but we have to pay for more computaitonal time for higer order MIMO systems as given in Table 1.

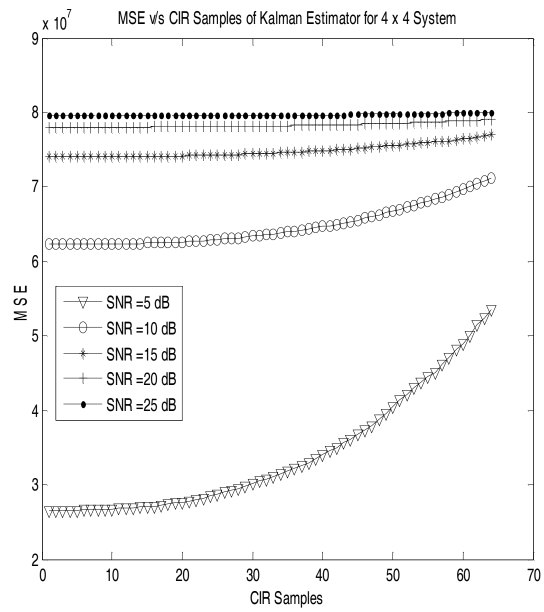

Fig. 2: MSE vs CIR Samples of Kalman Estimator for 4×4 System

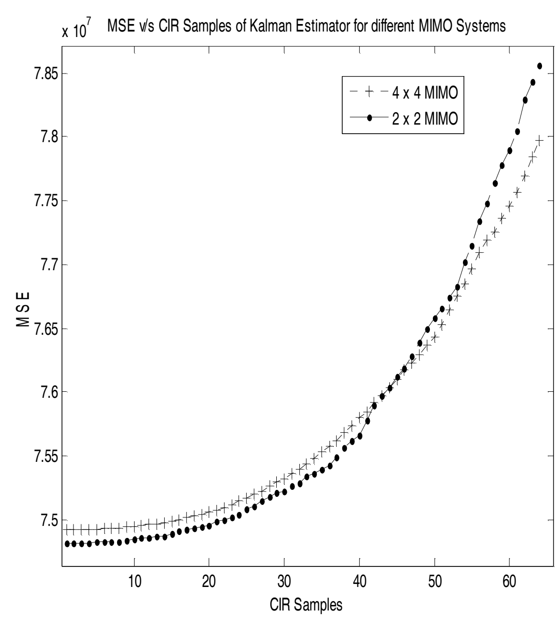

Fig. 3: MSE vs CIR Samples of Kalman Estimator for different MIMO Systems

For LSE initially estimated channel, the complexity increases by 97% as we go from 2×2 system to 3×3 system and for 4×4 system the complexity increases by 268%. For LMMSE initially estimated channel, the complexity increment is 88% for 3×3 system but it increases to 268% for 4×4 system. For 2×2 system and LSE initially channel estimator, as channel filter length is increased from 5 to 10, the complexity increases by 6% but for 20 CIR samples, there is 18% increment in computational time. For case of LMMSE estimator and 2×2 system, the increment in complexity is 65% by increasing the channel length from 5 to 10 and by further increase to 20 CIR samples the complexity increment is 68%. MSE behavior for LMMSE-Kalman Estimator is given in Fig. 4. As compared to LSE-Kalman Estimator, the performance remains same for almost 35-40 CIR samples but after that the performacne degradation is significant as compared to LSE-Kalman estimator for further increments in channel lengths. The performance as a function of both SNR and CIR Samples is shown in Fig. 5.

For different number of multi-path channel taps, the performance of Kalman Estimator is shown in Fig. 6. The effect of changing the number of multi-paths is most prominent for higher SNR values as compared to low SNR values. By increasing the number of channel taps considered for channel estimation, the peformance also goes on degrading as for larger number of channel taps, the noise effect is also more severe. The performance of Kalman Estimator for different MIMO systems is shown in Fig. 7. The performance also improves for higher order MIMO systems but here again this better performance comes at the cost of more complexity. The computational time of both LSE-Kalman and LMMSE-Kalman Estimators for different MIMO systems is shown in Table 2. For 2×2 system and LSE-Kalman Estimator, there is 15% more complexity while increasing the channel taps from 5 to 10 and there is 20% more complexity when 20 channel taps are considered. For 5 channel taps and LSE-Kalman Estimator, the complexity increases by 15% when taking 3×3 system and 38% when taking 4×4 MIMO system as compared to 2×2 system. But for LMMSE-Kalman Estimator, 19 % more complexity is observed for 3×3 system and for 4×4 MIMO this becomes 61%. The combined effect of SNR and channel taps on MSE is shown in Fig. 8.

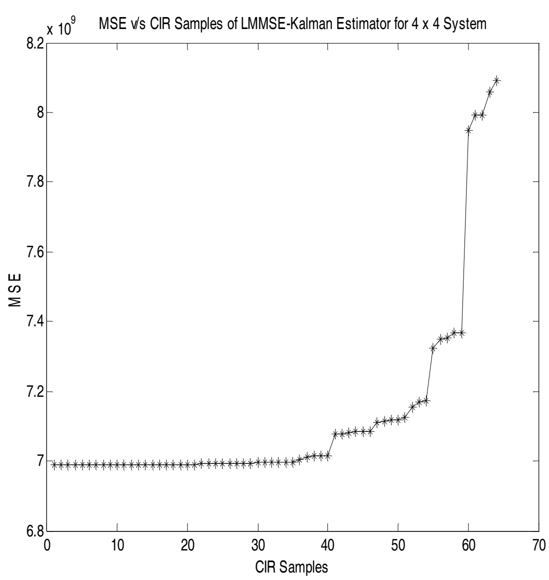

Fig. 4: MSE vs CIR Samples of LMMSE-Kalman Estimator for 4×4 System

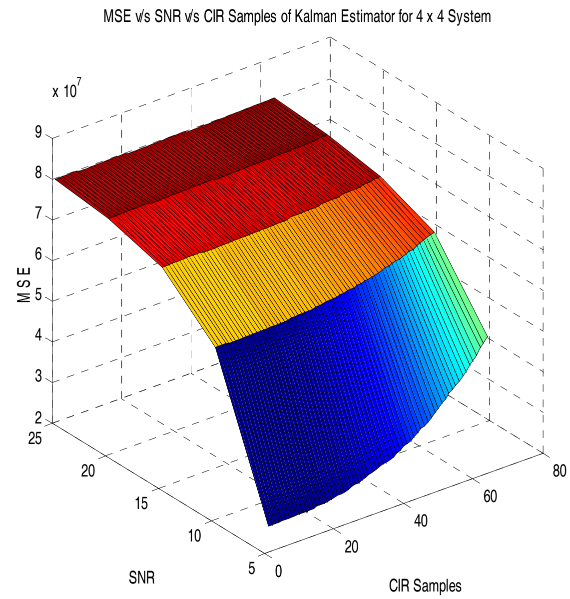

Fig. 5: MSE vs SNR vs CIR Samples of Kalman Estimator for 4×4 System

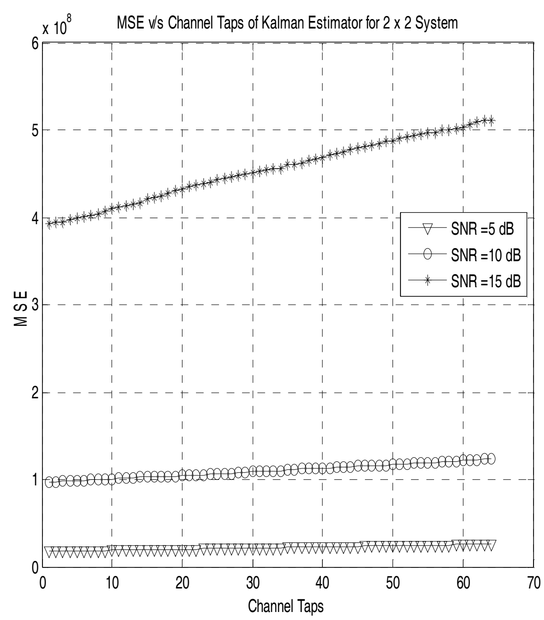

Fig. 6: MSE vs Channel Taps of Kalman Estimator for 2×2 System

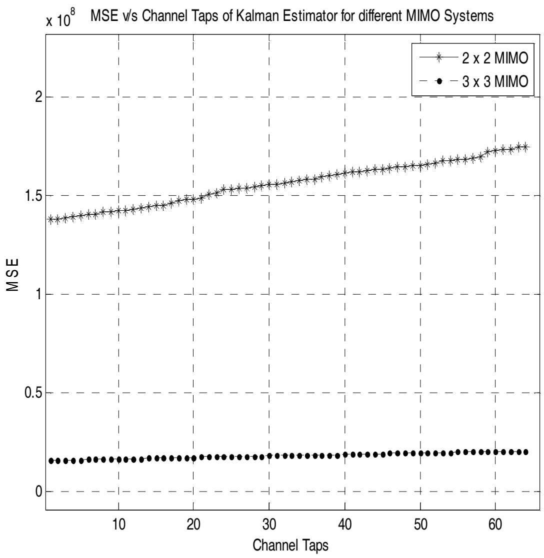

Fig. 7: MSE vs Channel Taps of Kalman Estimator for different MIMO Systems

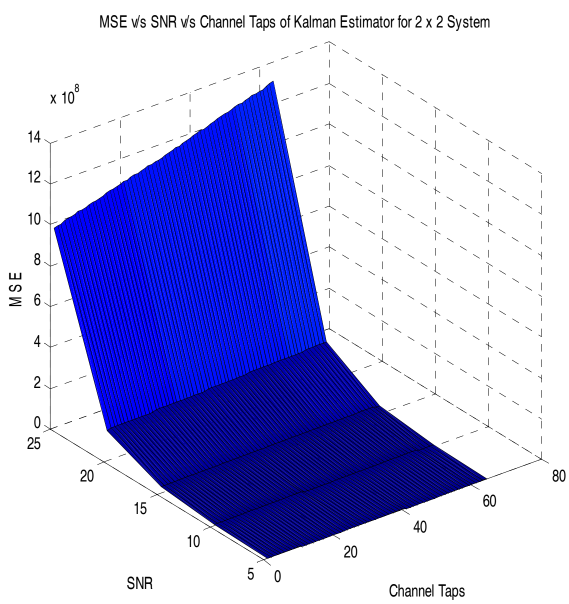

Fig. 8: MSE vs SNR vs Channel Taps of Kalman Estimator for 2×2 System

V. CONCLUSION

In this paper Kalman Filtering adaptive algorithm is used for channel estimation according to the physical layer parameters of LTE-Advanced. Two parameters, channel filter length and channel taps, are used for the performance evaluation of Kalman Estimator. Acceptable performance is achieved for 10-15 CIR samples for low SNR values but for higher SNR operating conditions, the performance becomes independent of channel filter length. For small channel filter length, MIMO system with small order results in better formance but as we increase the length of channel filter beyond 40-45 CIR Samples higher order MIMO system outperforms low order system. When Kalman algorithm is applied on LMMSE estimated channel, then performanc remains acceptable for CIR Samples less than 40 , after this value performance degrades significantly. For low SNR, the effect of varying channel taps is not significant on performance but for high SNR this effect is prominent. For better performance with less complexity, small channel filter lengths and small number of multi-paths with low order MIMO systems are optimized.

REFERENCES

[1] Krystian Safjan, Valeria D'Amico, Daniel Bultmann, David Martin, Ahmed Saadani, Hendrik, "Assesing 3GPP LTE-Advanced as IMT-Advanced Technology: The WINNER + Evaluation Group Approach", IEEE Communications Magazine, February 2011.

[2] Panayiotis Kolios, Vasilis Friderikos, Katerina Papadaki, "Future Wireless Mobile Networks: Energy Consumption and Resource Utilization in Mechnical Relaying", IEEE Vehicular Technology Magazine, March 2011.

[3] Saqib Saleem, Qamar-ul-Islam, "Performance Evaluation of Linear Channel Estimation Algorithms for MIMO-OFDM in LTE-Advanced", IJECS International Journal of Electrical and Computer Sciences, Vol.11, Issue.3, June 2011.

[4] Saqib Saleem, Qamar-ul-Islam, "Transform-Based Channel Estimation Techniques for LTE-Advanced", Journal of Computing, Vol.3, Issue.4, April 2011.

[5] S.M. Riazul Islam and Kyung Sup Kwak, "Winner-Hopf Interpolation Aided Kalman Filter-Based Channel Estimation for MB-OFDM UWB Systems in Time Varying Dispersive Fading Channel", ICACT, Feb.7-10,2011

[6] F.Wan, W-P Zhu, M.N.S Swamy, " Channel Estimation of Pulse-Shaped Multi-Input Multi-Outpu Orthiginal Frequency Division Multiplexing Systems", IET Communications, Vol.4, Issue.17, pp-2104-2114, 2010

[7] Ye Li, Jack H.Winters and Nelson R.Sollenberger, "MIMO-OFDM for Wireless Communications: Signal Detection with Enhanced Channel Estimation", IEEE Transactions on Communications, Vol.50, No.9, September 2002

[8] Wen Xing.Li, Ping Li, Xing Liu, Chai Feng, "Semi-Blind Channel Estimation for MIMO-OFDM System", Third International Conference on Measuring Technology and Mechatronics Automation, 2011

[9] Gordon L.Stuber, John R.Barry, Steve Mclaughlin, Ye Li, Mary Ann Ingram, Thomas G.Pratt, "Broadband MIMO-OFDM Wireless Communications", Proceedings of the IEEE, Vol.92, No.2, February 2004

[10] Saqib Saleem, Qamar-ul-Islam, "Channel Estimation using Adaptive Filtering for LTE-Advanced", IJCSI International Journal of Computer Science Issues, Vol.8, Issue.3, No.2, May 2011

TABLE 1: COMPLEXITY COMPARISON OF KALMAN ESTIMATOR FOR DIFFERENT MIMO SCHEMES

CIR Samples	2×2 (μsec)		3×3 (μsec)		4×4 (μsec)	
	LS- Kalman	LMMSE- Kalman	LS- Kalman	LMMSE- Kalman	LS- Kalman	LMMSE- Kalman
5	213	315	420	594	785	1000
10	227	522	448	784	837	1200
20	253	530	680	928	1100	1600

TABLE 2: COMPLEXITY COMPARISON OF KALMAN ESTIMATOR FOR DIFFERENT MIMO SCHEMES

Channel Taps	2×2 (sec)		3×3 (sec)		4×4 (sec)	
	LS-Kalman	LMMSE- Kalman	LS- Kalman	LMMSE- Kalman	LS- Kalman	LMMSE- Kalman
5	0.0026	0.0028	0.0030	0.0031	0.0036	0.0042
10	0.0030	0.0032	0.0031	0.0035	0.0037	0.0050
20	0.0032	0.0040	0.0041	0.0045	0.0043	0.0060