International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 14 (2015) pp 33914-33918
© Research India Publications. http://www.ripublication.com

EXTENDED KALMAN FILTER FOR CHANNEL ESTIMATION COMBINED WITH DECISION FEEDBACK EQUALIZER FOR VERY HIGH MOBILITY SYSTEM

Harsha Damodaran
Department of ECE
Amrita Vishwa Vidyapeetham
Coimbatore, India
e-mail: harsha.7d@gmail.com

Mr.Sudheesh.P, Dr.M.Jayakumar
Department of ECE
Amrita Vishwa Vidyapeetham
Coimbatore, India
e-mail: p_sudheesh@cb.amrita.edu

***Abstract*— Training sequence based channel estimation in combination with Decision Feedback Equalizer (DFE) is used for OFDM based communication receivers. Channel estimation is performed based on Extended Kalman Filter (EKF) algorithm where a two-step predictor corrector mechanism is carried out. In very high mobility environment for LTE downlink usual channel estimation algorithms are incapable due to its nonlinear nature. So an EKF is used for the estimation of complex-valued channel impulse response from the received signal in the non linear environment where the velocity is very large. EKF jointly estimates both time varying channel parameters as well as time correlation coefficients.. Furthermore a DFE is also modeled for eliminate the Inter Symbol Interference (ISI) and for better performance. Performance is evaluated by plotting Mean Square Error (MSE) as well as Bit Error rate (BER).**

Keywords*— *channel estimation, Extended Kalman Filter, Decision Feedback Equalizer.

I. INTRODUCTION

When a signal is transmitted from source to destination, certain characteristics of the physical channel will affect the signal information. So at the receiver there should be a mechanism to monitor the incoming signal and perform certain operations in order to recover back the original message signal. Characteristics of the channel refer to the properties such as impulse response. The signal reached at the receiver end describes additional information like fading of the signal, Doppler effects, scattering etc.

Multi path effect will cause reflections of the actual signal at the receiver section. So for identifying the proper channel, an estimation algorithm is necessary.

For coherent detection of the received signals an efficient method should be adopted in the receiver section for estimating channel parameters in case of Orthogonal Frequency Division Multiplexing (OFDM) signals. For random varying channels, there will be unpredictable fluctuations in the channel gain. By the method of training sequence insertion in the OFDM sequence, channel estimation is performed. Channel estimation techniques are explained in [3] [4] [5] for OFDM block that works on algorithms like Least Square (LS) and Minimum Mean Square Error (MMSE). Here Extended Kalman Filter (EKF) based channel estimation is performed along with a Decision Feedback Equalizer (DFE).

In channel estimation the present channel is predicted using the previous available information. i.e., the channel frequency response is predicted prior to the time actually signal reaches the receiver end. In case of a training sequence aided OFDM transmission, an initial training sequence is transmitted. Using this training sequence and the received symbol, the channel impulse response is calculated using which the next channel impulse response is predicted and corrected by using an extended Kalman filter. Since the channel conditions vary rapidly i.e., due to non-linearity, for estimating the impulse response we go for extended Kalman filter rather than a Kalman filter. The time dependent channel is modeled like an auto regressive process and the dependent variables are real and in between 0.98 to 1 for slow varying channel and in between 0-1.5 for fast varying channels. The Extended Kalman Filter will jointly estimate the time varying channel (i.e., channel impulse response) as well as the time correlation co-efficient (or auto regressive parameters). Usually channel estimation is initially performed based on a known series of bits which are unique to the transmitter and receiver.

The orthogonality among the subcarriers within the OFDM symbols is disturbed due to the rapidly varying channel and this will cause Inter Carrier Interference (ICI) among the sequence. The channel variations include multi path fading, scattering etc. So an equalizer [1] is used at the receiver section for eliminating the inter symbol interference caused due to the channel. The velocity considered is very large (ie., at the range of [0-300Km/hr]) which makes the system a nonlinear one. Since nonlinear scenario is considered, a more complex equalizer is needed. So a decision feedback equalizer [2] is used. The DFE is based on the MMSE algorithm [4] which significantly reduces further interference and rotation of constellation. The channel impulse response is required for equalizers. So a channel estimation algorithm using extended Kalman filter along with a decision feedback equalizer is incorporated here.

Kalman filters are a set of predictor corrector combination which is used to find out the unmeasured state. The Kalman filter works on consecutive cycles of predictions and filtering. An extended Kalman filter is a nonlinear version of the Kalman filter. Based on certain available information an estimate of the system state is obtained. The Kalman filter will effectively minimizes the state errors occurred during the estimation. Thus it is called an optimal filter. Kalman filter is the best approximate for linearly varying systems but majority of the real systems are nonlinear in nature. So after some modifications a Kalman filter is used in cases of nonlinear systems. The Kalman filter with this non linearity case incorporated is the extended Kalman filter which is used in the estimation purpose of several applications. First order extended Kalman filter is commonly used. There are higher order EKF but they are performance beneficial only if the measurement noise is very small.

EKF is also a two-step process where the unmeasured state and covariance at current time is estimated in the prediction step. In the second step the predicted value is corrected by incorporating the recent measured values and the Kalman gain term and gives the most appropriate value.

The EKF is optimal only if the state and measurement model are linear. If the filter is modeled incorrectly or if the initial approximation is wrong, the filter will diverge which leads to erroneous estimates. Also if there is no stabilizing noise, the filter will be inconsistent. As there is a positive feedback mechanism in the Taylor series approximation in the filter equations, if the estimate is good then the approximation will generally be accurate and the next estimate will be good and if the estimate is poor then the next estimate will also be poor. Most of the Kalman filter applications include tracking purpose. Since not an optimal filter, EKF is implemented based on certain assumptions. Thus the co variances estimated do not match with the true covariance. The filter will diverge if the consecutive linearization is not a good approximation of the linear model in the uncertainty domain.

II. METHODOLOGY

A. *Background Study*

The channel estimation scenario has already been implemented by many of the latest trends in the communication industry. Some of the commonly used estimation methods are briefly explained by the following section. This will give an idea about the various combinations of different prediction and correction methods that are used in the field of estimation of channel. The channel estimation schemes adapted in various scenarios like OFDM, CDMA…etc. uses either an equalizer based approach or a filter based approach such as the Kalman filter.

A simple and less complex implementation of channel estimator can make use of a linear equalizer as the estimation mechanism. In the present communication systems like LTE networks demands a highly stable and accurate prediction of channel variables to attain quality of service. The Adaptive Equalizer based on this approach proposed by Teyan Chen, [1] et.al. shows a less complex operation of the order of O (N (K+M)) where M and K are the length of channel estimator and equalizer and N is the number of iterations performed per samples. This proposed method gives the equalizer module to have a multiplication and division free estimation of equalizer coefficients. Thus the hardware complexity is reduced and a nice performance index is achieved. The Kalman filter based channel estimation scheme is one of the most popular and highly efficient schemes used for OFDM signals now a day. The system described in the paper by M. Huang, et.al. [4] has the ability to track the channel parameters where the channel responses are characterized by the sparse propagation path. The variation in signal subspace leads to an unconstrained minimization problem in the estimation scenario. The Kalman filter based approach reduces this to an extent. The design is also scaled up for the use in multi antenna scenarios.

The paper by Wei Li, et.al. [4] proposes a different system where a hybrid channel estimation scheme is used for the OFDM modulated signals. The hybrid method consists of two different estimation schemes which are combined together to give a more performance intense system. This clubs together a coarse estimator and a fine estimator. The coarse estimator uses the classical estimation methods which incorporates the channel impulse response and channel frequency offset based on prediction. This is done with the help of the received training sequence. The fine estimator includes polynomial interpolation estimation with a combined Decision Feedback Equalizer (DFE) which in turn reduces the residual effects present in the signal. As per the article the system is supposed to enhance the receiver performance by a noticeable amount. Another much more convenient system described by Christos Komninakis, et.al. [8] incorporates the Kalman based estimation and the decision feedback equalizer in to one single channel estimator. This was intended for MIMO channels. The channel variations are tracked by the Kalman filter based estimation method and the tracking is aided by the equalization by a DFE. This complex system gives a higher tracking efficient MIMO fading ISI channels.

The various algorithms used for prediction has their own pros and cons which make them unique in behavior. The system with single equalizer or single Kalman filter lacks accurate prediction of next channel subspace. The combined estimators such as hybrid method and Kalman with DFE are in capable of producing highly accurate predictions of channel variations. But this also lacks to incorporate the nonlinear behavior exhibited by the current communication channels which demands the need of another system which is capable of identifying the channel variations of a nonlinear channel and predict the next channel subspace accurately.

B. *OFDM Signal*

OFDM is most prominent technologies for high rate data transmission. The subcarriers of the OFDM signals are orthogonal and overlapped in the frequency spectrum so as to achieve a high efficiency. The data to be sent are distributed among different subcarriers in the OFDM signal. Each of the subcarrier is modulated with a modulation scheme before transmitting. An OFDM symbol with N subcarriers is considered. And the modulation scheme adopted is Quadrature Amplitude Modulation (4QAM).

C. *Channel Model*

A Rayleigh channel is considered for the case of OFDM propagation. Since the environment considered is nonlinear where the propagation due to line of sight is practically impossible. The channel is implicitly considered to be invariable within an OFDM sample and is assumed to vary for different OFDM samples. A sample channel environment model is given in table 1. [7] The frequency of operation is 3GHz.

The frequency response of the channel impulse response can be represented as,

$$h_k = [h_k[1]h_k[2]h_k[3]\ldots\ldots h_k[N]]^T \tag{1}$$

TABLE 1 Sample Channel Model

Tap no.	**Delay(µs)**	**Avg path gains (dB)**
1	0	-2.7248
2	0.13702	-4.4513
3	0.26304	-11.0552
4	0.37906	-18.4500
5	0.53208	-18.2176

III. PROPOSED SYSTEM

Based on training sequence method, a known data sequence is sent initially. Let $x = [x_1\ x_2\ x_3\ldots\ldots x_N]^T$ is the training sequence corresponding to the k^{th} OFDM sample which is already known. $y = [y_1\ y_2\ y_3\ldots\ldots\ y_N\ ]^T$ be the signal received at the receiver section. As the signal passes through the channel, the channel parameters will affect the transmitted signal. The received signal can be expressed in the following way,

$$y = X * h + w \tag{2}$$

where h denotes the channel frequency response, X denotes the diagonal matrix of x and w is the effect of noise added from the channel which is the Additive White Gaussian Noise (AWGN).

In channel estimation the channel frequency response of all the subcarrier signals are estimated using the estimated frequency response obtained by sending the training sequence.

Using the channel frequency response estimated, a DFE is modeled so as to detect the actual transmitted signal through the channel. The Equalizer will cause the ISI to reduce to a greater extend.

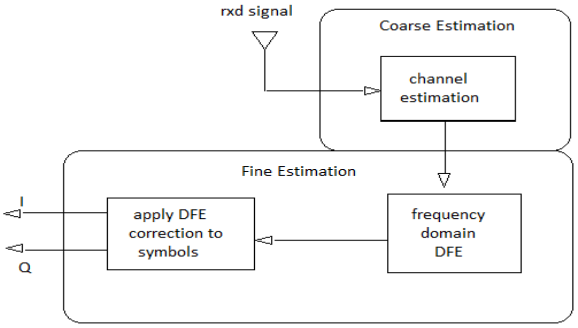

Figure.1 Proposed block diagram

A. *EKF algorithm*

A Single Input Single Output (SISO) OFDM signal is considered where the channel frequency response of a known pilot signal is estimated using the extended Kalman filter and within the block each of the incoming OFDM symbol and each of its subcarriers the frequency response is estimated using the previously estimated frequency response.

The main purpose of decision feedback for channel estimation process is to improve performance. The estimated variables in the channel estimation process are updated continuously by the Kalman filter and the Decision Feedback Equalizer at each subcarrier.

The state space model of the time dependent channel is defined as follows:

$$h_{k+1} = A_k\ h_k + v_k \tag{3}$$
$$y_k = H\ x_k + w_k \tag{4}$$

Where h_t represents the state variable which is the channel frequency response and A is the unknown state transition matrix. w_t and v_t are the AWGN which are independent of each other. y_t is the observation vector.

The channel frequency response and the time varying parameter are jointly estimated. So a variable z is introduced as a single matrix for representing the augmented state. A is the sparse matrix where a represents the unknown parameters of A.

$$z_k=[a_k^T h_k^T]^T \tag{5}$$

EKF algorithm works in such a way that linearizing the nonlinear parameter A and then perform the standard Kalman algorithm on the linearized model. Linearization is performed on the basis of approximating Taylor series expansion. Thus the state space equation can be modeled as,

$$z_{k+1} = F_k \; z_k + u_k \qquad (6)$$
$$y_k = H \, z_k + w_k \qquad (7)$$

EKF works on a predictor corrector basis [7]. In the prediction step the state is estimated and the estimated state is updated in the correction step by multiplying with the Kalman gain. The channel frequency response is estimated initially from the training symbol which is used for estimating the upcoming data symbols. This process is done iteratively until most accurate value is obtained.

$$\hat{z}_{k|k-1} = f(z_{k-1}) = \begin{bmatrix} \hat{a}_{k-1} \\ \hat{A}_{K-1}\hat{h}_{k-1} \end{bmatrix} \qquad (8)$$

$$P_{k|k-1} = F_{k-1} P_{k-1} F_{k-1}^H + Q_u = \begin{bmatrix} P_{a,k|k-1} & P_{ah,k|k-1} \\ P_{ah,k|k-1}^H & P_{h,k|k-1} \end{bmatrix} \qquad (9)$$

$$K_k = \begin{bmatrix} P_{ah,k|k-1} \\ P_{h,k|k-1} \end{bmatrix} X_k^H (X_k P_{h,k|k-1} X_k^H + Q_w)^{-1} \qquad (10)$$

$$\hat{z}_k = \hat{z}_{k|k-1} + K_k (y_k - X_k \hat{h}_{k|k-1}) \qquad (11)$$

$$P_k = P_{k|k-1} - K_k [0 \; X_k] P_{k|k-1} \qquad (12)$$

Using the above algorithm the channel frequency response is estimated for the known training sequence sent. h is known only at the pilot symbol. In the data symbol period the $\hat{h}$ is estimated by decision directed mode by the decoder and this $\hat{h}$ is returned back to the EKF in order to replace the pilot h. so the decoder will estimate $\hat{h}$ at each iteration from the previously estimated h.

The noises supplemented by the channel are assumed to be Additive White Gaussian Noise (AWGN). The covariance matrices of the Kalman filter are selected in such a way as by considering small variances and error due to linearization. The effect of noise is larger at low SNR which makes the estimated response less accurate and as SNR value increases the addition of noise is less and will cause a better estimation result.

B. *Decision Feedback Equalizer*

The received signal is distorted in the transmission process by the effect of channel conditions and the noise effects. So there is chance to occur ISI in the received signal sequence. So there should be an efficient mechanism at the receiver end for mitigating the effect of ISI on the received signal [2]. For this purpose an Equalizer is used which will remove the ISI on the signal and reproduce the transmitted filter with less error as possible. Since the scenario assumed here is non linear in nature, a DFE is used for equalization. Multi path effect will also demand the necessity of an equalizer at the receiver end.

In DFE the transmitted symbol is detected at the receiver section and based on the detected signal, the ISI removals of the future signals are also performed.

IV. SIMULATION RESULTS

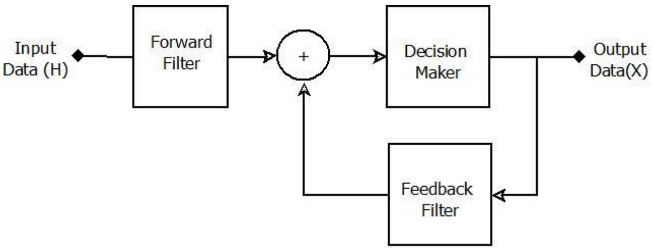

Fig. 2. DFE block

Simulation is conducted to confirm the performance of EKF with Decision Feedback Equalizer. A Rayleigh channel is modeled where the channel parameters are defined in the table 1. Quadrature Amplitude Modulation (QAM) scheme is employed.

Simulations are done for various noise levels with Signal to Noise ratio (SNR) changeable from 0 to 25 dB and for velocities ranging from 0 to 300 Km/hr. The Mean Square Error (MSE) obtained for the proposed EKF based channel estimate with DFE is low. The lower value of MSE implies the filter's ability to estimate the Channel Frequency Response (CFR) accurately and to correctly track the channel parameters in a non linear scenario.

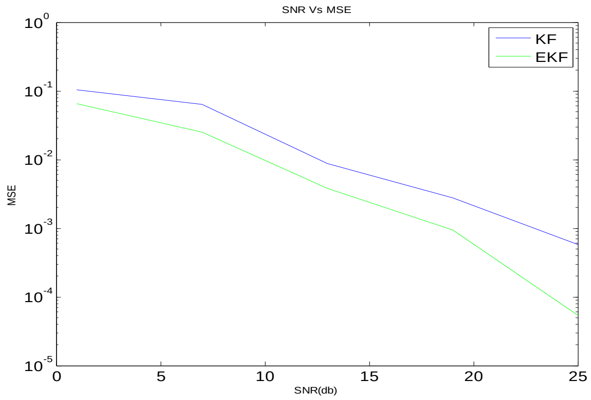

Fig. 3. MSE vs SNR for KF and EKF

Fig.3 is the plot of Mean Square Error for various SNR values in the case of both Kalman and Extended Kalman Filter. The plot shows that the EKF performs best in non linear environment. The error value is less for EKF for all SNR than the KF. The graph shows a difference of 1dB in error for EKF which shows that EKF performs well in non linear case.

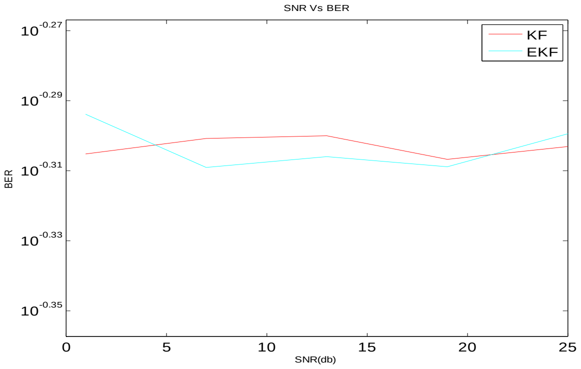

Fig. 4 BER vs SNR for KF and EKF

Fig.5 shows the MSE for various SNR at various velocity ranges. It can be seen that at low velocity [0-100Km/hr] the error value is very less and at large velocity [200-300Km/hr] also the error is less which shows that the EKF can track the channel response at very large velocity also. At low SNR the error value is comparatively large and at higher SNR better error performance is achieved.

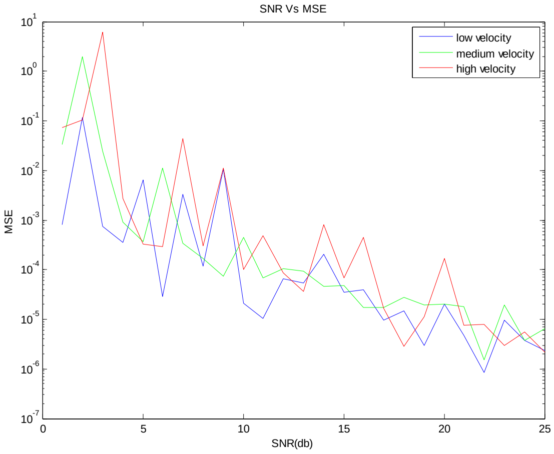

Fig.5 MSE for various velocities

V. CONCLUSION

This article deals with the channel estimation of OFDM symbols based on EKF for non linear environment. Since dealing with very large velocity, a Doppler shift is introduced and hence the system is nonlinear. A Rayleigh channel is considered. Both channel tap parameters and the time varying coefficients are jointly estimated based on EKF algorithm. EKF will give a much better approximation of state prediction in the non linear case which is considered. Furthermore a DFE is also modeled along with the channel estimator. The performances are validated in terms of MSE and BER. Simulation results show that even at very large velocity EKF performs well.

References

[1] T. Chen, Yuriy V. Zakharov, *Senior Member, IEEE*, and Chunshan Liu, “Low complexity channel estimate based adaptive linear equalizer”, IEEE Signal Processing Lett., vol. 18, no. 7, July 2011

[2] Athanasios A. Rontogiannis, *Member, IEEE*, and Kostas Berberidis, *Member, IEEE. “*Efficient Decision Feedback Equalization for Sparse Wireless Channels*”*, IEEE Trans. On Wireless Commun. , vol. 2, no. 3, may 2003

[3] Osvaldo Simeone, *Student Member, IEEE*, Yeheskel Bar-Ness, *Fellow, IEEE*, and Umberto Spagnolini, *Senior Member, IEEE, “*Pilot-Based Channel Estimation for OFDM Systems by Tracking the Delay-Subspace”, IEEE Trans. on Wireless Commun., vol. 3, no. 1, jan 2004

[4] Wei Li, Yue Zhang, Li-Ke Huang, Carsten Maple, and John Cosmas, “Implementation and Co-Simulation of Hybrid Pilot-Aided Channel Estimation With Decision Feedback Equalizer for OFDM Systems”, IEEE Trans On Broadcasting, Vol. 58, No. 4, Dec 2012by Tracking the Delay-Subspace”, IEEE Trans. on Wireless Commun., vol. 3, no. 1, jan 2004

[5] J. Beek, O. Edfors, M. Sandell, S. Wilson, P. Borjesson, On channel estimation in OFDM systems. in Proc. of IEEE Vehicular Technology Conference’95 2, 815–819 (1995). Chicago, Il M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

[6] Rocco Claudio Cannizzaro*y*, Paolo Banelli*y*, and Geert Leusz University of Perugia, D.I.E.I., 06125 Perugia, Italy. *z* Delft University of Technology, EEMCS Faculty, 2628 CD Delft, The Netherlands, “Adaptive Channel Estimation for OFDM Systems with Dopplerspread”

[7] X.Dai, W.Zhang, Jing Xu, J.E. Mitchell and Yang Yang,” Kalman interpolation filter for channel estimation of LTE downlink in high-mobility environments”, EURASIP Journal on Wireless Communications and Networking 2012.

[8] C. Komninakis, Christina Fragouli, Ali H. Sayed, Richard D. Wesel,*”* Multi-Input Multi-Output Fading Channel Tracking and Equalization Using Kalman Estimation*”,* IEEE Trans. on Signal Processing, vol. 50, no. 5, May 2002