Comparative Study of Channel Estimation Algorithms under Different Channel Scenario

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ABSTRACT
The principle objective of this work is to enhance the knowledge about channel estimation and to compare the existing channel estimation techniques under different channel conditions. Normally the received signal is corrupted by the channel (Multipath, ISI). The estimation of a time-varying multipath fading channel is a difficult task for the receiver. Its performance can be improved if an appropriate channel estimation filter is used according to the prior knowledge of the fading channel. In this work the two popular estimation algorithms, viz., LMS and RLS are studied with respect to AWGN, Rician and Rayleigh channels. The simulation is performed in MATLAB platform.

General Terms
Vehicle-to-vehicle (V2V/ VTV) communication, intelligent transport systems (ITS), adaptive algorithm, equalizer, channel, fading channel, multipath.

Keywords
LMS (Least Mean Square), RLS (Recursive Least-Squares), AWGN (Additive white Gaussian noise), Rayleigh Fading Channel & Rician Fading Channel.

1. INTRODUCTION
A channel is a medium, which transfer data or information from transmitter to receiver. Channels include the physical medium like free space, fiber, waveguides etc. The features of any physical medium is that, the transmitted signal is corrupted in various way by frequency and phase distortion, inter symbol interference, thermal noise etc and the receiver receives the corrupted signal [1].

Estimation means prediction, detection or approx calculation. Channel estimation is simply defined as the process of characterizing the effect of the physical channel on the input sequence. We can say a channel is well estimated when its error minimization criteria is satisfied [1]. Channel estimation gives the basic idea of the effect of the physical channel on the input sequence of the receiver [2]. The error can be minimized by equalization technique. It helps to produce a channel to ideal channel when voice, data and video can pass through the channel. Channel estimation algorithms explain the behavior of the channel and allow the receiver to approximate the impulse response of the channel. The use of vehicle-to-vehicle (V2V/ VTV) communication will be an integral part of intelligent transport systems (ITS) [3], and work on ITS is growing substantially in recent years [4].

Vehicular ad-hoc network removes the dependence on cellular network for vehicle-to-vehicle communication system. Public safety is also another part of V2V communication [5].

The V2V system needs to support at least one wireless local area network technology to support non-safety applications,, e.g., IEEE 802.11a/b/g. In contrast to non-safety applications, safety applications are usually of broadcast nature. Safety applications are supported by specific V2V network and transport protocols, and are normally based on IEEE 802.11p [4]. The IEEE 802.11p radio technology is directly derived from IEEE 802.11a with some modifications to adapt to vehicular environments. It occupies 75 MHz of the licensed spectrum, from 5.85 to 5.925 GHz is used as part of the intelligent transportation system for dedicated short range communications (DSRC) in the USA [6]. The IEEE 802.11p, Wireless Access in Vehicular Environment (WAVE) standardization process originates from the allocation of the Dedicated Short Range Communications (DSRC) spectrum band in the United States and the effort to define the technology for usage in the DSRC band [7].

In our previous works [8, 9], ITS channel modeling [8] and a comparison of equalization techniques for WCDMA, WLAN and WiMAX [9] are presented. In this paper, four channel estimation algorithms (LMS, RLS, MMSE, Kalman filter) are compared. Then the case studies presented for an OFDM based systems.

Rest of the paper is organized as follows: A detailed literature survey is presented in section 2. Channel estimation algorithm is given in section 3. Generalized channel is discussed in section 4. Channel in ITS is given in section 5. Simulation and results are discussed in section 6. Finally, in section 7 concludes the paper.

2. LITERATURE SURVEY
Jones et al. [10] have introduced adaptive filters through the example of system identification using the LMS algorithm. Haykin [2] discussed the concept of the adaptive filter algorithms that are implemented with FIR filter structures and their variety of applications in those systems where minimal information is available about the incoming signal. Vanderveen et al. [11] have focused on the joint estimation of angles and relative delays of multipath propagation signals emanating from a single source and received by a single antenna array. Rontogiannis et al. [12] have proposed a parametric method for estimating the unknown multipath channel impulse response

(CIR) in a semi-blind manner. An approach for estimating the model parameters based on sample covariance from data disturbed by discrete-time measurement noise has been proposed for large-scale fading channels in wireless communication systems in [13]. A generalized RAKE (G-RAKE) receiver is proposed in [14] for suppressing intra cell interference in the downlink of a DS-CDMA system employing orthogonal codes. Wei et al. [15] have proposed a new kind of Rake receiver based on modified Kalman filter algorithm (MKFA). This kind of receiver, simultaneously considers the channel gain factor and the noise time-variable statistics characteristic, which can speed up the convergence rate and enhance the track performance of the algorithm. Olama et al. [16] have proposed an algorithm which consists of filtering based on the Kalman filter to remove noise from data, and identification based on the filter-based expectation maximization (EM) algorithm to determine the parameters of the model which best describe the measurements.

3. CHANNEL ESTIMATION ALGORITHM

Mainly two types of adaptive algorithms are used in channel estimation purpose. The algorithms are Least-Mean Square (LMS) & Recursive Least-Squares (RLS).

3.1 Least-Mean Square (LMS) Algorithm

LMS algorithm uses the estimates of the gradient vector from the available data. LMS incorporates an iterative procedure that makes successive corrections to the weight vector in the direction of the negative of the gradient vector which eventually leads to the minimum mean square error. Compared to other algorithms LMS algorithm is relatively simple [17].

Input: A random process x(n);

FIR filter of weight: (w0, w1…wN-1);

Filter output: $Y(n) = w^T x(n)$;

Error signal: $e(n) = d(n) - y(n)$

Where d(n) is the desired output.

From the method of steepest descent, the weight vector equation is given by:

$$W(n) = W(n) + 1/2\mu[-\nabla(E\{e^2(n)\}] \qquad (1)$$

Where μ is the step-size parameter and controls the convergence characteristics of the LMS algorithm.

In the method of steepest descent the biggest problem is the computation involved in finding the values r and R matrices in real time. The LMS algorithm on the other hand simplifies this by using the instantaneous values of covariance matrices r and R instead of their actual values i.e.

$$R(n) = x(n)x^T(n) \qquad (2)$$

$$r(n) = d^*(n)x(n) \qquad (3)$$

Therefore the weight update can be given by the following equation:

$$w(n+1) = w(n) + \mu x(n)[d^*(n) - x^T(n)w(n)]$$
$$= w(n) + \mu x(n)e^*(n) \qquad (4)$$

$$e(n) = d(n) - y(n) \qquad [n = 0\, to \quad final] \quad (5)$$

$$Y(n) = w^T(n)x(n) \qquad (6)$$

Equation number (4) & (6) are respectively known as weight update & filtering operation equation.

3.2 Recursive Least Square (RLS) Algorithm

The Recursive least squares (RLS) adaptive filter is an algorithm which recursively finds the filter coefficients that minimize a weighted linear least squares cost function relating to the input signals. This is in contrast to other algorithms such as the least mean squares (LMS) that aim to reduce the mean square error [18].

The RLS algorithm for a *p*-th order RLS filter can be summarized as,

Parameters:

$p =$ Filter order

$\lambda =$ Forgetting factor

$\delta =$ Value of initialize $P(0)$

Initialization: $w_n = 0$

$P(0) = \delta^{-1}\mathrm{I}$ Where I is the (p+1)-by-(p+1) identity matrix

Computation: For n= 0,1,2,…….

Then the weight update can be given by the following equation:

$$w(n) = w(n-1) + \alpha(n)g(n) \qquad (7)$$

Where,

$$\alpha(n) = d(n) - w(n-1)^T x(n) \qquad (8)$$

$$g(n) = P(n-1)z(n)\{\lambda + x^T(n)P(n-1)x(n)\}^{-1} \qquad (9)$$

$$P(n) = \lambda^{-1}P(n-1) - g(n)x^T(n)\lambda^{-1}P(n-1) \qquad (10)$$

And,

$$x(n) = \begin{bmatrix} x(n) \\ x(n-1) \\ . \\ . \\ . \\ x(n-p) \end{bmatrix} \qquad (11)$$

4. CHANNEL

There are three basic types of channels considered for this work. The vehicle-to-vehicle (V2V) channels estimation are compared with cellular channels. Performance of three channels, viz., AWGN, Rayleigh Fading Channel, Rician Fading Channel in V2V communication environment is evaluated through simulation.

Multipath fading is a significant problem in communications. In a fading channel, signals experience fades (i.e., they fluctuate in their strength). When the signal power drops significantly, the channel is said to be in a fade. This gives rise to high bit error rates (BER).

4.1 AWGN Channel:

An Additive white Gaussian noise (AWGN) channel adds white Gaussian noise to the signal, when the signal passes through it. In this channel model the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density and a Gaussian distribution of amplitude. Fading, frequency selectivity, interference, nonlinearity or dispersion are not the part of AWGN model. It generates simple and tractable mathematical models. Those models are useful for gaining insight into the underlying behavior of a system before these other phenomena are considered **[19]**.

In case for many satellite and deep space communication links, the AWGN model is very good. This model is not useful for most terrestrial links because of multipath, terrain blocking, interference, etc. However AWGN is used to simulate background noise of the channel under study, in addition to multipath, terrain blocking, interference, ground clutter, etc [19].

Fig 1: AWGN channels at least one existing LOS.

The AWGN channel is represented by a series of outputs S_i at discrete time event index *i*. S_i is the sum of the input R_i and noise, Q_i, where Q_i is independent and identically-distributed and drawn from a zero-mean normal distribution with variance *n* (the noise). The Q_i are further assumed to not be correlated with the X_i [19].

$$Q_i \approx N(0,n) \qquad S_i = R_i + Q_i \qquad (12)$$

The channel capacity *C* for the AWGN channel is given by:

$$C = \frac{1}{2}\log(1+\frac{P}{n}) \qquad (13)$$

Where *P* = maximum channel power.

4.2 Rician Fading Channel:

Rician fading is a stochastic model. It is used for radio propagation anomaly caused by partial cancellation of a radio signal by itself, the signal arrives at the receiver by several different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening). Rician fading model applicable where one dominant propagation along a line of sight between the transmitter and receiver; typically a line of sight (LOS) signal is much stronger than the others signal. In Rician fading, the amplitude gain is characterized by a Rician distribution [20].

K and Ω are the two parameters of Rician fading channel. *K* is the ratio between the power in the direct path and the power in the other, scattered, paths. Ω is the power in the direct path. The received signal amplitude (*not* the power of the received signal) *R* is then Rice distributed [20].

$$f(x) = \frac{2(K+1)x}{\Omega}\exp(-K-\frac{(K+1)x^2}{\Omega})I_0(2\sqrt{\frac{K(K+1)}{\Omega}}x) \quad (14)$$

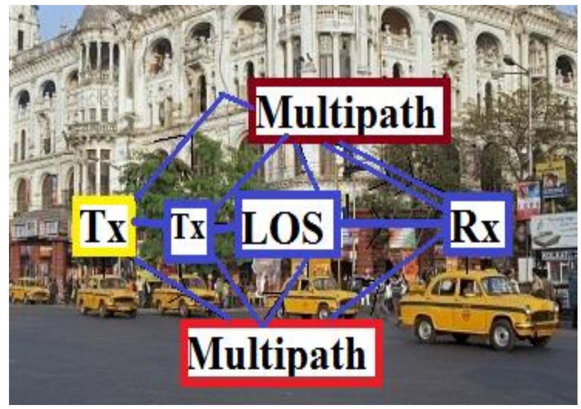

Fig 2: Rician Fading Channel with existing one LOS

4.3 Rayleigh Fading Channel:

Rayleigh fading channel is a statistical model. It assumes the magnitude of a signal. This model is used for the effect of a propagation environment on a radio signal, such as that used by wireless devices.

When the signal has passed through such a transmission medium (communications channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables [21].

Rayleigh fading is viewed as a sensible model for tropospheric and ionospheric signal propagation and it is used for the effect of heavily built-up urban environments on radio signals. If there is no dominant propagation along a line of sight between the transmitter and receiver, there Rayleigh fading model is applicable. In case of one dominant line of sight, Rician fading may be more applicable.

Rayleigh fading is a sensible model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver. If there is sufficiently much scatter, the channel impulse response will be well-modeled as a Gaussian process irrespective of the distribution of the individual components. Transmitted signal of Rayleigh fading model is affected by multipath. If there is no dominant component to the scatter, then such a process will have zero mean and phase evenly distributed between 0 and 2π radians. The envelope of the channel response will therefore be Rayleigh distributed [21].

Calling this random variable R, it will have a probability density function:

$$P_R(r) = \frac{2r}{\Omega} e^{-r^2/\Omega} \qquad r \geq 0 \qquad (15)$$

Where $\Omega = E(R^2)$

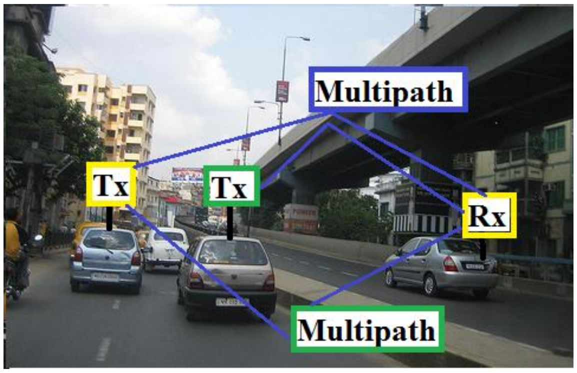

Fig 3: Rayleigh Fading Channel with no existing LOS.

5. CHANNEL IN ITS

The development of the future V2V and Vehicle-to-Infrastructure (V2I) communications systems imposes strong radio channel management challenges due to their decentralized nature and the strict Quality of Service (QoS) requirements of traffic safety applications.

- In ITS channel, scattering can occur around both the TX and the RX, on the other hand base station is usually free of scatter.
- The distance over which communications can take place is much smaller in ITS channels (< 100 m) than in typical cellular scenarios (~ 1 km).
- In cellular communication only Tx or Rx is moving, for ITS both are moving.
- ITS operates most high carrier frequency (5.8-5.9GHz), whereas Cellular communication operates mostly 700-2400MHz.
- The ITS ad-hoc communications are peer-to-peer communications, thus the transmitter and receiver are at the same height and the same environment. On the other hand in cellular communication the base station is high above the street level and the mobile station is at the street level. Thus the dominant propagation mechanisms of the multipath components are different.

6. SIMULATION AND RESULTS

6.1 Input signal:

From this simulation of all the adaptive filters (LMS & RLS) comparison we observed that the RLS exhibits minimum error.
A random signal is taken as an input which is modulated by QPSK modulator. The constellation diagram of input signal is shown in Fig 4.

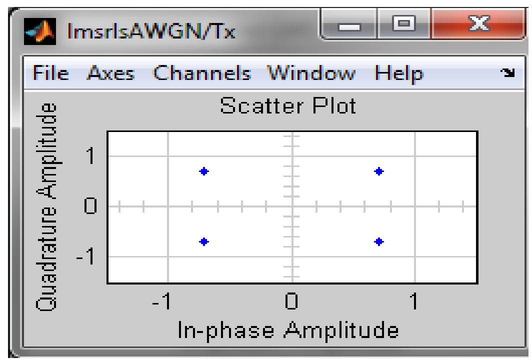

Fig 4: Transmitted signal.

After modulation signal is sent through a channel. Here three different types of channel are used. They are AWGN channel, Rayleigh fading channel & Rician fading channel.

6.2 Channel

6.2.1 Case I. AWGN Channel.

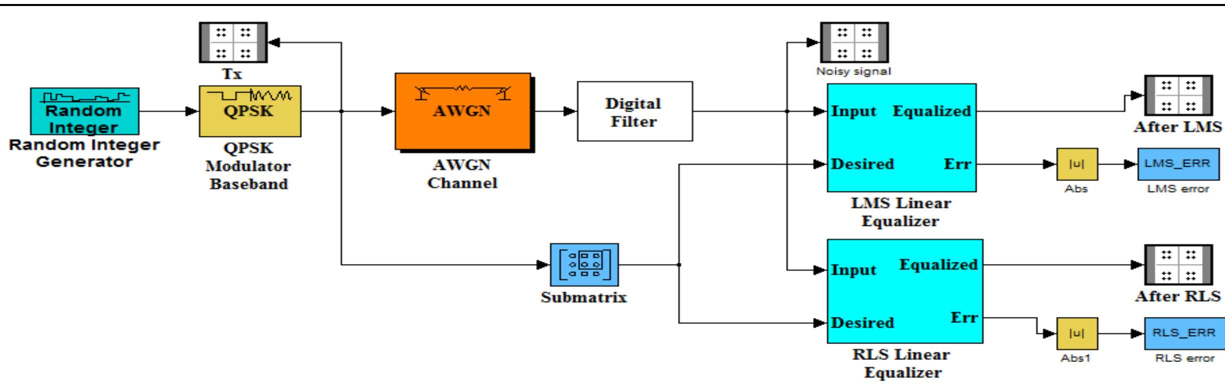

Fig 5: Block diagram AWGN Channel Model.

The AWGN channel model is referred in v2v communication where no multipath or echo can affect the transmitted signal. In this channel only some noise is added with the transmitted signal, which is received by the receiver side vehicle.

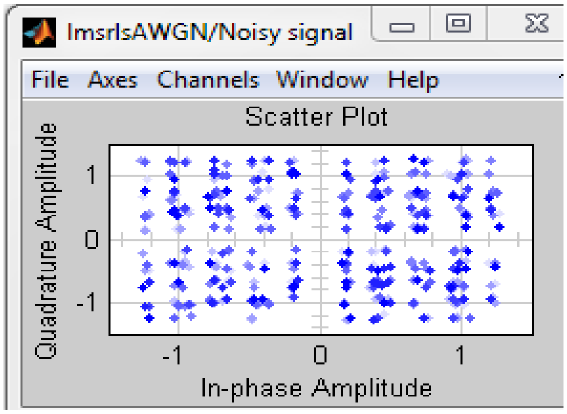

Fig 6: Received signal at the receiver end.

Then the received signal compared with the desired signal and equalized it with respect to the desired signal. This process is done by adaptive equalizer which may be LMS or RLS equalizer. The received signal equalized by LMS equalizer then the scatter plot of the output signal looks like as Fig 7.

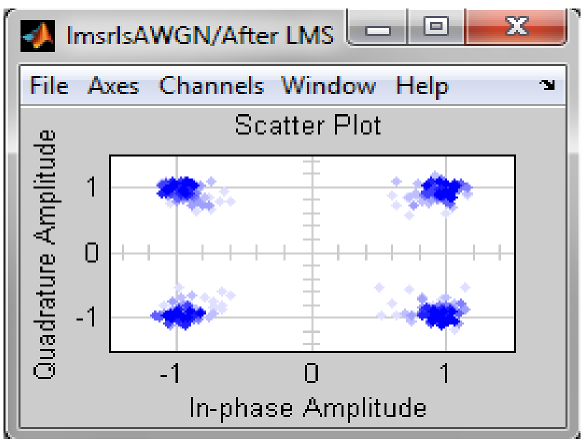

Fig 7: Equalized signal (LMS).

Similarly the RLS equalizer output is shown in the Fig 8. It is observed that RLS equalizer takes less time to equalize the signal compare to the LMS equalizer.

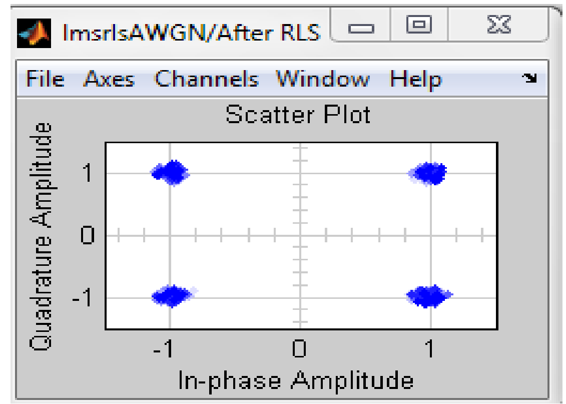

Fig 8: Equalized signal (RLS).

We see in the Fig 9 that the error curve of RLS is decreasing faster than LMS error curve.

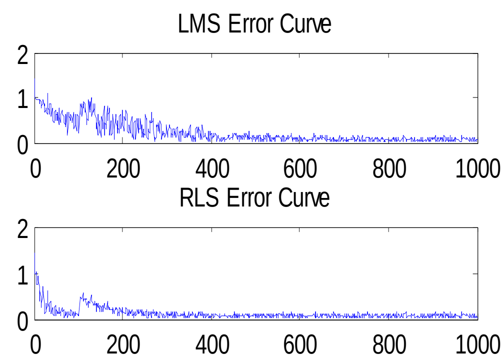

Fig 9: Simulated error curve comparison of LMS & RLS equalizer.

6.2.2 Case II. Rician Fading Channel.

Transmitted signal of Rician fading model is affected by multipath. Rician fading occurs when one of the path is much stronger than the others. This path is called line of sight (LOS) signal. In Rician fading, the amplitude gain is characterized by a distribution. The model behind Rician fading is similar to that for Rayleigh fading; expect that in Rician fading a strong dominant component is present. Fig 10 is the diagram of Rician fading model and fig 11 plot of noisy signal at the receiver end are shown respectively.

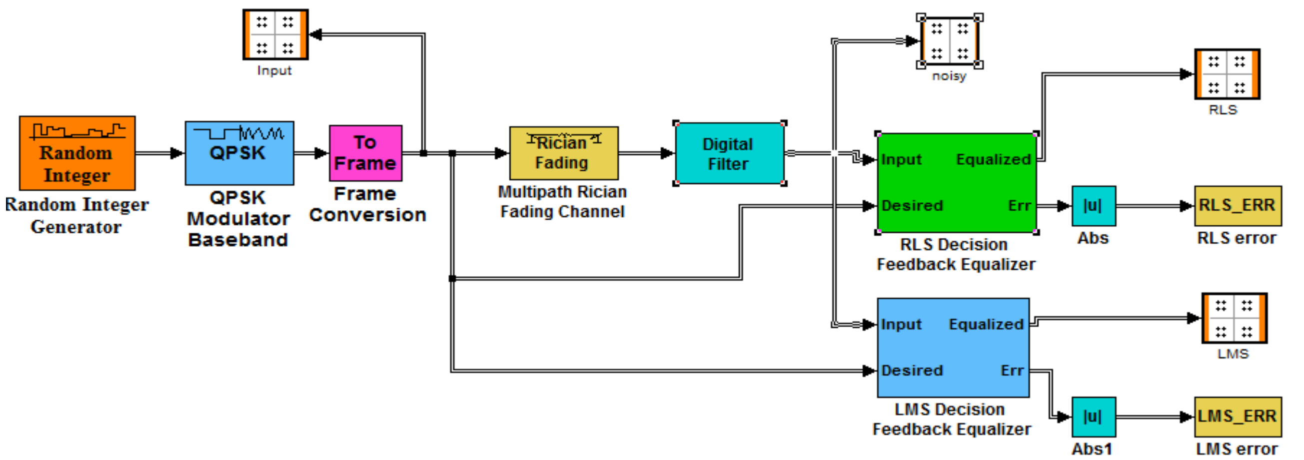

Fig 10: Block diagram of Rician Fading Channel.

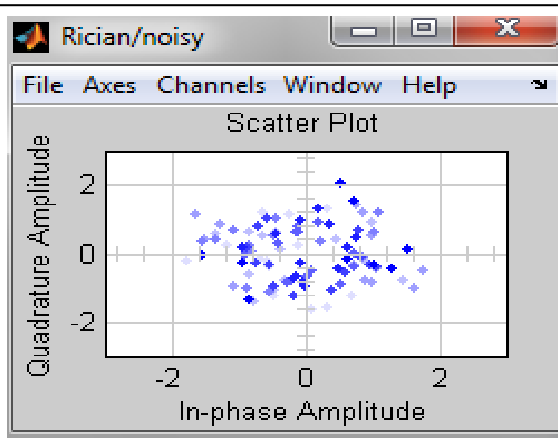

Fig 11: Noisy signal at the receiver end.

The scatter plot of LMS equalized signal is shown in Fig 12.

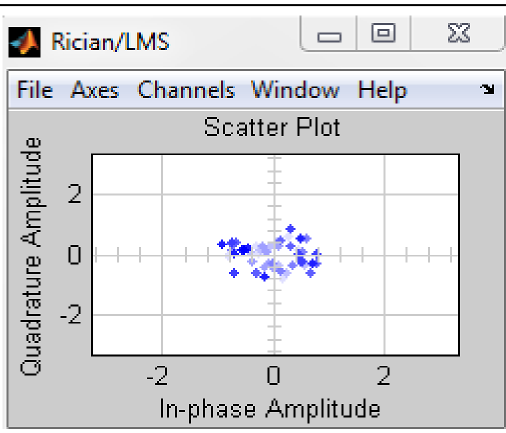

Fig 12: LMS equalized signal.

And the RLS plot is shown below.

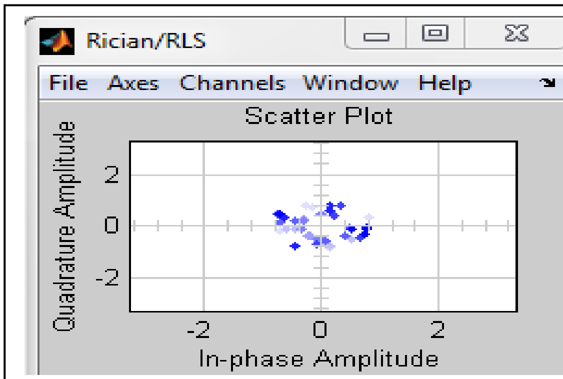

Fig 13: RLS equalized signal.

In this case for the Rician fading model, it is again prove that RLS equalizer is more efficient to reduce the error.

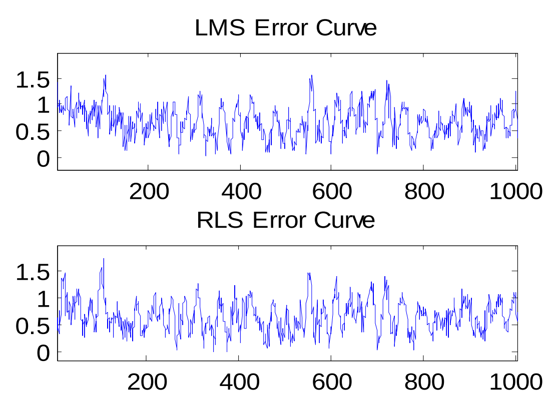

Fig 14: LMS & RLS equalizer error curve.

6.2.3 Case III: Rayleigh Fading Channel.

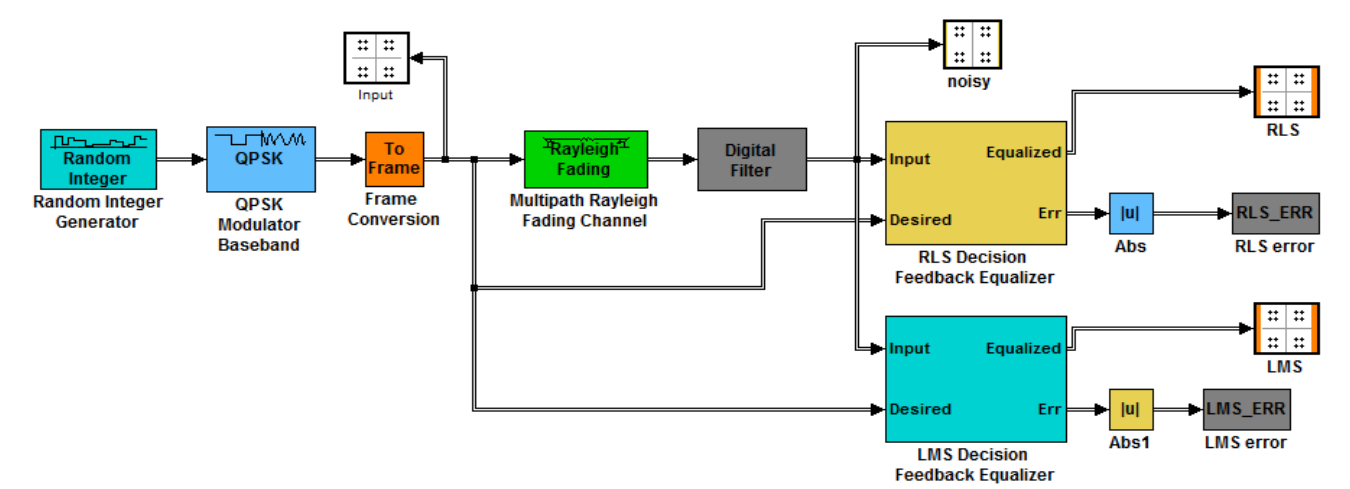

Fig 15: Block diagram of Rayleigh fading channel model.

Rayleigh fading is caused by multipath reception. The mobile antenna receives large number of reflected scattered waves. The scatter plot of the received signal is shown in Fig 15.

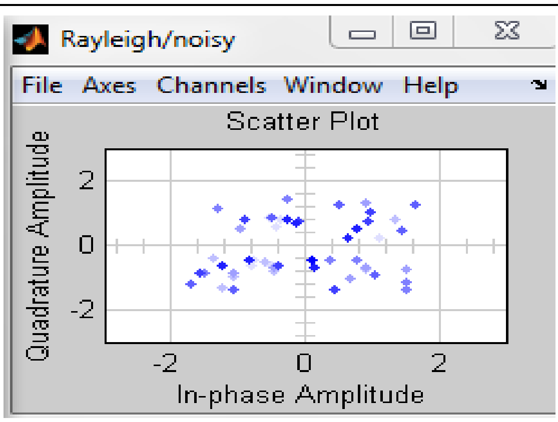

Fig 16: Received Signal

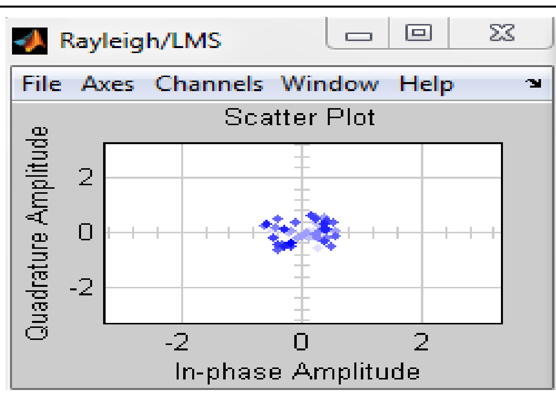

Fig 17: LMS equalized signal.

Similarly as the case I & case II RLS equalizer takes less time to equalize the noisy signal. Fig 17 is the scatter plot of LMS equalized signal. RLS equalized signal of Rayleigh fading channel model is shown in the Fig 18.

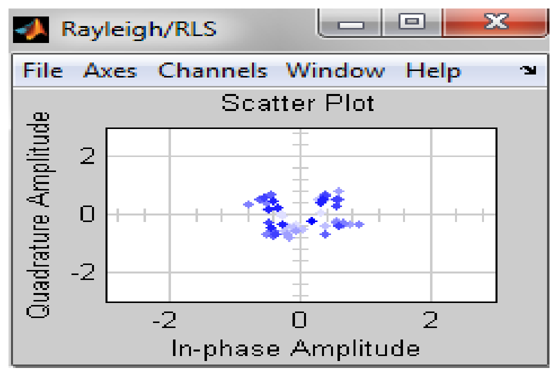

Fig 18: RLS equalized signal.

Due to the fading of signal the error value of Rayleigh Fading model is more than AWGN channel model. The error plot of the both adaptive equalizer (LMS & RLS) are given below in the Fig 19.

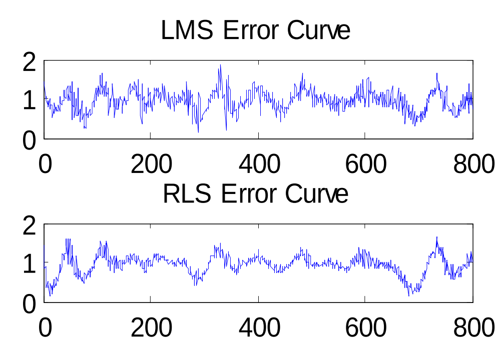

Fig 19: LMS & RLS equalizer error curve.

7. CONCLUSIONS

The performance of LMS and RLS algorithms are studied with respect to AWGN, Rician and Rayleigh channels. The results of the simulation show that the received signal is equalized faster if

RLS is used as channel estimation algorithm compared to LMS. This is due to the fact that standard deviation of RLS is less compared to LMS.

Table 1. Comparison of Mean Error and Standard Deviation

Channel	Mean Error		Standard Deviation	
	LMS	RLS	LMS	RLS
AGWN	0.2250	0.1183	0.239	0.1311
Rician Fading	0.8435	0.8491	0.7772	0.783
Rayleigh Fading	0.9485	0.9273	0.2590	0.2474

From this comparison, we see that RLS algorithm generates less error than LMS algorithm. And AWGN channel produces smallest amount of error value. The error value increases for changing channel from AWGN Channel to Rician Fading Channel, & Rician Fading Channel to Rayleigh Fading Channel. On the other hand mathematical computation is simple and straight forward for LMS compared to RLS and hence implementation of LMS algorithm is easier.

8. REFERENCES

[1] Safaya .R "A Multipath Channel Estimation Algorithm using a Kalman filter" online available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.142.1549&rep=rep1&type=pdf

[2] Haykin, S. (1996), "Adaptive Filter Theory, 3/e", Prentice Hall.

[3] ASTM E2213, "Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems 5GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications, http ://wwwastmorg, January 2006.

[4] ITS project website. Nov. 2006. [Online]. Available: http://www.its.dot.gov/index.htm

[5] T. L. Doumi, "Spectrum considerations for public safety in the United States," IEEE Commun. Mag., vol. 44, no. 1, pp. 30–37, Jan. 2006.

[6] IEEE P802.11p/D2.01, "Standard for Wireless Local Area Networks Providing Wireless Communications while in Vehicular Environment," Mar.2007.

[7] Daniel Jiang, Luca Delgrossi, "IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments", IEEE Vehicular Technology Conference, Singapore, 11-14 May, 2008. DOI:10.1109/VETECS.2008.458

[8] S.Dhar, R.Bera, R.B. Giri, S.Anand, D.Nath, S.Kumar (2011), "An Overview of V2V Communication Channel Modeling", in proceedings of ISDMISC'11, 12-14 April, 2011, Sikkim, India.

[9] Rabindranath Bera, Sanjib Sil, Sourav Dhar and Subir K. Sarkar (2008), "Wi-Fi, WiMax and WCDMA A comparative study based on Channel Impairments and Equalization method used" International Symposium on Microwave, December 2008, Bangalore, India

[10] Jones et al. "Adaptive Filtering: LMS Algorithm"-02.06.2005 16:10 filterdesign exercise in matlab (http://cnx.rice.edu/content/m10623/latest/).

[11] Vandeveen, M.C., Vanderveen, A.J. and Paulraj, A. (1998), "Estimation of Multipath Parameters in Wireless Communications", IEEE Transactions on Signal Processing, Vol: 46, No. 3, pp (682-690), March 1998; doi: 10.1109/78.661335

[12] Rontogiannis,A.A., Berberidis,K., Marava,A. and Palicot, J. (2005), "Efficient semi-blind estimation of multipath channel parameters via a delay decoupling optimization approach", Signal Processing 85 (2005) 2394–2411, Elsevier; doi:10.1016/j.sigpro.2005.02.018

[13] Mossberg, M., Larsson,E.K. and Mossberg, E. (2009), "Long-term fading channel estimation from sample covariances", Automatica 45 (2009) 1126-1133, Elsevier; doi:10.1016/j.automatica.2008.12.013

[14] Bottomley,G.E., Ottosson, T. Wang, Y.P.E. (2000), "A Generalized RAKE Receiver for Interference Suppression" IEEE Journal on Selected Areas in Communication, VOL. 18, NO. 8, pp(1536 - 1545), AUGUST 2000; doi: 10.1109/49.864017

[15] Wei, L., Dong, J., Ye , F. and Yang, S. (2009), "Research on a new kind of Rake-MKFA receiver based on DS-UWB system", 5th International Conference on Wireless Communications, Networking and Mobile Computing, 24-26 Sept. 2009, WiCom '09; doi: 10.1109/WICOM.2009.5305739

[16] Olama, M.M. Djouadi, S.M. Charalambous, C.D. (2009) , "Stochastic Differential Equations for Modeling, Estimation and Identification of Mobileto-Mobile Communication Channels" , IEEE Transactions on Wireless Communications, Volume: 8, Issue: 4, pp(1754 – 1763), April 2009; doi: 10.1109/TWC.2009.071068

[17] Shetty k.k. "LEAST MEAN SQUARE ALGORITHM" http://etd.lib.fsu.edu/theses/available/etd-04092004-143712/unrestricted/Ch_6lms.pdf

[18] RLS online available at: http://en.wikipedia.org/wiki/Recursive_least_squares_filter

[19] Additive white Gaussian noise online available at: http://en.wikipedia.org/wiki/Additive_white_Gaussian_noise

[20] Rician fading online available at: http://en.wikipedia.org/wiki/Rician_fading

[21] Rayleigh fading online available at: http://en.wikipedia.org/wiki/Rayleigh_fading