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Lattice-Reduction-Aided Equalization for V2V Communication Channel

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Abstract

World is moving towards the implementation of massive MIMO based communication system and that forces the researchers to design low complexity receiver architecture. MIMO system performance in Vehicular ad hoc networks (VANETs) is a popular research topic. And to support Vehicle-to-vehicle (V2V) communication in high speed mobility condition, it required to have reliable and secure of communication. This paper deals with the performance evaluation of the low complex LLR-MMSE receiver in terms of the channel capacity and bit error rate improvement. In this paper we have considered V2V Spatial Channel Model (SCM) and Nakagami-m channel model for the performance evaluation. The performance has been evaluated based on the mathematical calculation and simulated results. And also performance comparison between the conventional linear MIMO receivers with the lattice reduction aided MIMO receivers have been presented.

Index Terms: MIMO, Capacity, ZF, MMSE, LLR.

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1. Introduction

From the point of view of road safety, driver protection, on the way communication etc., vehicle-to-vehicle (V2V) communication researches have gain significant importance in research world. And also today's advancement in communication technologies are moving towards the exchange of high data rate multimedia information. The growing demand of super-fast communication system leads to the development of massive

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MIMO system.

The main bottleneck of this system is its complexity. And researchers have point out the importance of designing the low complex receiver system. As we know that sub-optimal receiver like linear receiver suffers from the loss of mutual information [1-3], therefore in case of a large scale MIMO system, complex Lenstra, Lenstra and Lovasz (CLLL) algorithm [4] is beneficial. And system analysis with CLLL aided receivers is become utmost important [5-9]. As in [1], capacity of MIMO using LLR-ZF receiver has been analysed. In this paper, authors have presented the improvement in MIMO channel capacity due to CLLL aided MMSE receiver (LLR-MMSE). The improvement in the channel capacity is depends on the effective utilization of the orthogonalizing of the channel matrix. LLR algorithm improves the orthogonality deficiency of the channel matrix in comparison to linear receivers [10-11]. And this helps to improve the system performance significantly over the conventional linear receivers [12-14]but with reduction in complexity w.r. to optimal receivers.

As it is already proven that MMSE perform better than the ZF receiver, here in this paper we have considered MMSE as the basic functional equalizer technique. Here, in this paper, first we have calculated the channel capacity improvement factor for LLR-MMSE receiver over the MMSE receiver. Then we have presented the performance of the LLR-MMSE receiver through the simulation. This paper also present the performance of the system with the variation in Nakagami fading parameter m and correlation coefficient and also in SCM channel.

The remaining paper is presented as follows. Section II mathematical formulation for capacity of LR-aided MMSE receiver for the MIMO system. While Section III represents the comparative results to evaluate the performance. Section IV provides the conclusion remarks.

2. System Description

2.1. Spatial Channel Model:

The SCM [3rd Generation Partnership Project (3GPP), 2003; J. Salo et al, 2005] is a detailed model for simulating different fading environments. It considers a large number of cluster of scatters and each cluster corresponds to a different paths. Model consist of N_t element transmitter antennas and N_r receiver antennas and it generate $N_r \times N_t$ matrix of complex amplitudes channel. SCM channel model takes care of some important parameter like angle of arrival (AOA), angle of departure, delay spread, Doppler spread, antenna height, path loss fading characteristic, power delay profile etc. Each those paths are characterized by its own spatial channel parameters as mentioned above. And these path are assumed to be independent. Based on the channel characteristic, there are several environments such as suburban macrocell, urban macrocell, urban microcell.

2.2. Capacity of LR-aided MMSE receiver:

Let us consider a MIMO system with N_t transmitter and N_r receiver antennas. The received signal for a MIMO system can be represented by

$$y = Hx + w \quad (1)$$

Where H is the $N_r \times N_t$ complex wireless channel matrix, y represent the received signal for the given transmitted signal x . w represent the zero mean white Gaussian noise vector having size $N_r \times 1$. From the simplicity point of view, here we have considered that channel state information (CSI) is available at the receiver side but it is absent at the transmitter section.

Main aim of this paper is to analyse the capacity improvement due to LR aided MMSE receiver. Here authors have used complex LR technique. Main goal of LR aided system is convert the ill conditioned channel matrix H into a well-conditioned \tilde{H} by exploiting orthogonalization. LR algorithm produces the reduced

channel matrix $\tilde{H} = HT$, where T is unimodular matrix. Therefore, in case of a LR aided MIMO system, the overall system can be represented as,

$$y = HT(T^{-1}x) + w \quad (2)$$

The channel capacity for a conventional MMSE [15] system can be represented as,

$$C_{MMSE} = \log_2 \left[\frac{1}{(I_{N_r} + SNR.H^H H)^{-1}} \right] \quad (3)$$

The channel capacity of a LR aided MMSE receiver can be represented as

$$C_{MMSE}^{LR} = \log_2 \left[\frac{1}{(I_{N_r} + SNR.\tilde{H}^H \tilde{H})^{-1}} \right] \quad (4)$$

At high SNR condition, the factor $(I_{N_r} + SNR.H^H H)^{-1}$ can be further expressed as

$$\begin{aligned} (I_{N_r} + SNR.H^H H)^{-1} &= (SNR.H^H H)^{-1} - I_{N_r} (SNR.H^H H)^{-2} + O(SNR^{-3}) \\ &= (SNR.H^H H)^{-1} \left[1 - I_{N_r} (SNR.H^H H)^{-1} + O(SNR^{-2}) \right] \end{aligned} \quad (5)$$

Therefore, at high SNR condition, the capacity difference between LR-MMSE and MMSE can be expressed as,

$$\begin{aligned} C_{MMSE}^{LR} - C_{MMSE} &= \log_2 (SNR.H^H H) - \log_2 \left[1 - I_{N_r} (SNR.H^H H)^{-1} + O(SNR^{-2}) \right] - \log_2 (SNR.\tilde{H}^H \tilde{H}) \\ &+ \log_2 \left[1 - I_{N_r} (SNR.\tilde{H}^H \tilde{H})^{-1} + o(SNR^{-2}) \right] \end{aligned} \quad (6)$$

$$C_{MMSE}^{LR} - C_{MMSE} = \log_2 \left(\frac{\tilde{H}^H \tilde{H}}{H^H H} \right) + \log_2 \left(\frac{1 - I_{N_r} (SNR.H^H H)^{-1} + o(SNR^{-2})}{1 - I_{N_r} (SNR.\tilde{H}^H \tilde{H})^{-1} + o(SNR^{-2})} \right) \quad (7)$$

Equation (7) represent the capacity improvement due to LR-MMSE system.

3. Simulation Results

For the simulation purpose, authors have consider 4x4 MIMO system in correlated Nakagami-m and SCM channel environment. Here only the receiver side antenna correlation (ρ) have been considered and also channel state information is available only at the receiver side. The overall simulation results are presented in two sections: performance in Nakagami-m channel followed by SCM channel.

3.1. Nakagami-m Channel Model:

This section represents the performance of the MIMO system in Nakagami-m channel environment.

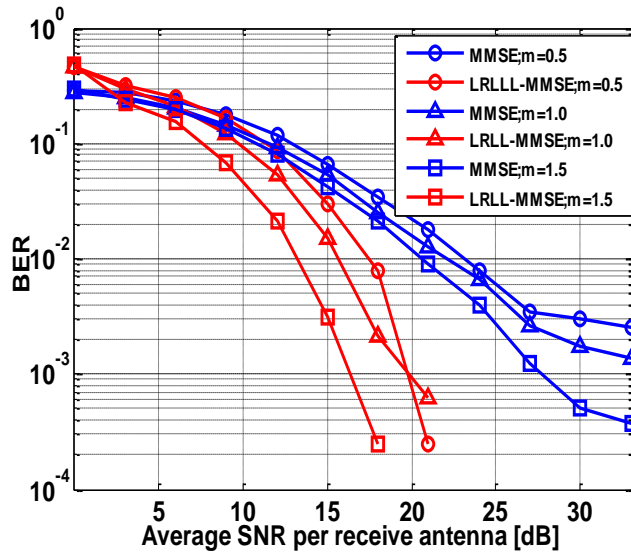


Fig.1. SNR Vs BER Curves for Different M.

As in figure 1, with increase in m value the BER performance of the system gets better. As represented in figure 3, for $m=1.5$, the required SNR to achieve a BER of 10^{-2} for all the systems are 13 dB (LRLLL-MMSE), 21 dB (MMSE), Therefore it clear that there is significant amount of SNR improvement in case of LRLLL aided system.

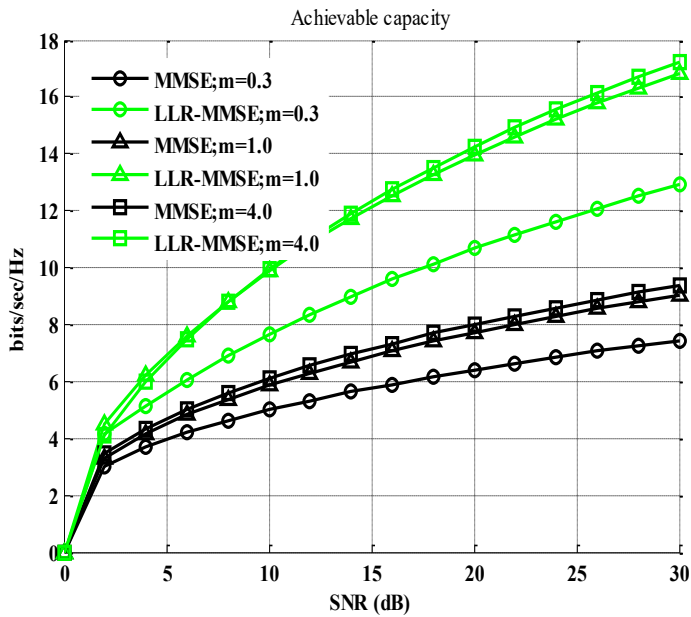


Fig.2. Channel Capacity with the Variation of m .

Table 1. Channel Capacity Comparison for 4x4 MIMO System.

Name of the receiver	Channel Capacity (bps/Hz) at SNR of 26 dB		
	m=0.3	m=1.0	m=4.0
MMSE	7.05	8.56	8.86
LLR-MMSE	12.08	15.79	16.14

As in Table 1, LLR-MMSE receiver boost the system performance effectively. Fig. 2 shows the comparative analysis of different receivers. It can also be seen that with the increase in SNR the performance gap between LLR-MMSE and MMSE increases. Let us consider the case for $m=0.3$, the channel capacity at low SNR region (considering SNR=4dB) the capacities for MIMO system with LLR-MMSE and MMSE receivers are 5.153bps/Hz and 3.67bps/Hz respectively. Therefore, the capacity gap is about 1.483 bps/Hz in low SNR region. Now, in same channel condition at high SNR region (considering SNR=26dB) the capacities for MIMO system with LLR-MMSE and MMSE receivers are 12.08bps/Hz and 7.055bps/Hz respectively. Therefore, the capacity gap is about 5.025 bps/Hz in high SNR condition.

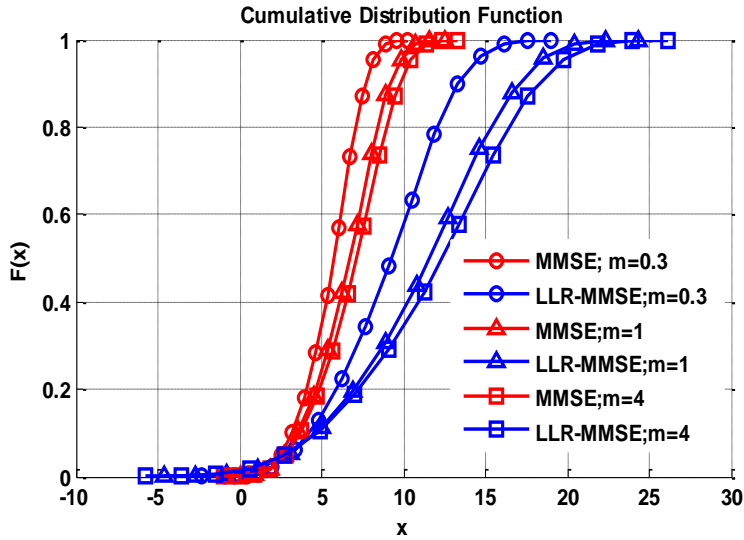


Fig.3. CDF of Channel Capacity with the Variation of m.

From above Fig.3, it is clear that m has a significant impact on the system performance. As in Fig. LLR-MMSE provides a capacity gain in comparison to other receivers.

3.2. With Spatial Channel Model (SCM):

In this section, the performance of the MIMO system has been analyzed in the SCM channel environment.

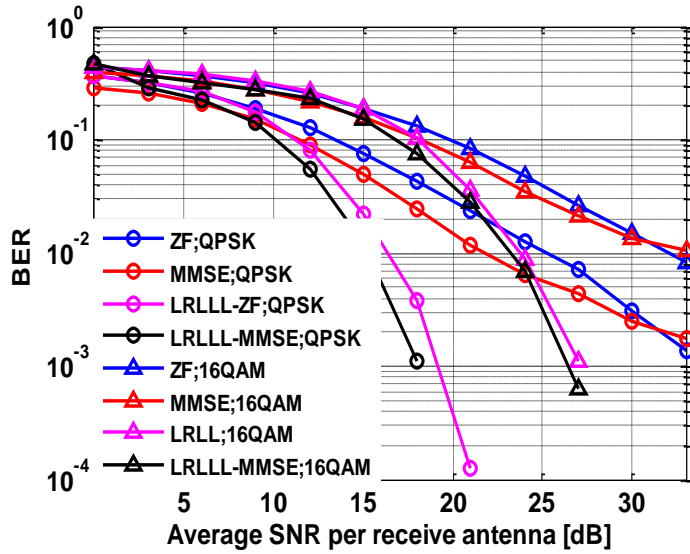


Fig.4. SNR Vs BER Curves for Different Modulations.

Fig. 4 represent the comparison of the performances of LRLLL concatenated ZF/MMSE receiver with conventional ZF and MMSE receiver with the variation modulation order. As in Fig. 4, for any modulation scheme ZF performs worst whereas LRLLL-MMSE performs best. Let us consider QPSK modulation for performance evaluation. To achieve BER of the order of $10e-2$, LRLLL-MMSE required 15 dB SNR whereas ZF needs SNR of 25dB. It shows by using LRLLL-MMSE receiver one can obtained a SNR gain of around 10dB.

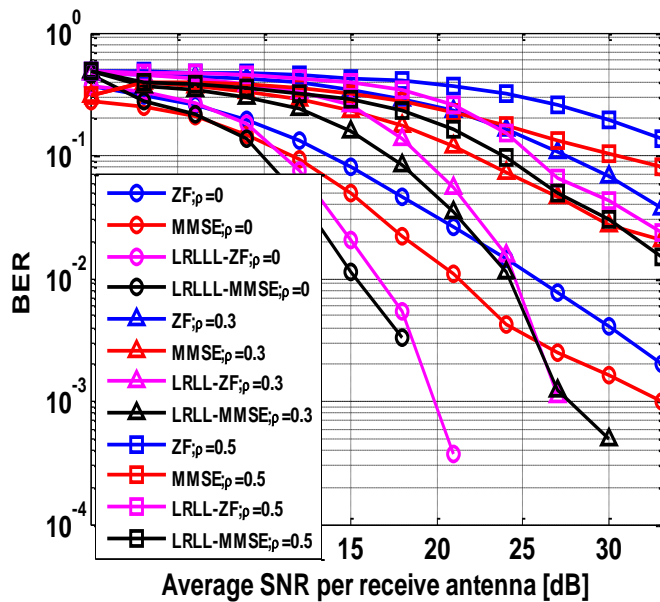


Fig.5. SNR Vs BER Curves for Different ρ .

Fig. 5 depicts the impact of the channel correlation coefficient on the system performance. It shows a significant improvement in system performance due to LRLLL-MMSE receiver.

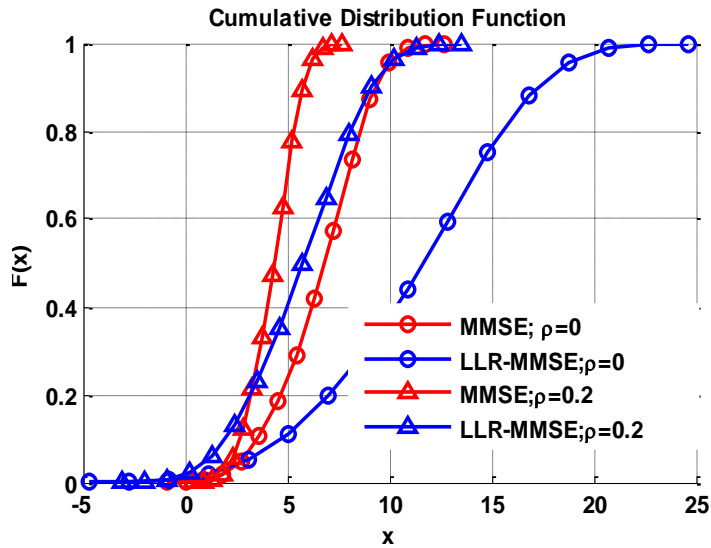


Fig.6. CDF of Channel Capacity with the Variation of ρ .

From above Fig. 6, it is clear that channel correlation coefficient having significant impact on the system performance. But LLR-MMSE performs much better than the conventional MMSE receivers. So, channel capacity improvement due to the CLLL aided receiver is prominent through the mathematical calculation and also the simulation results.

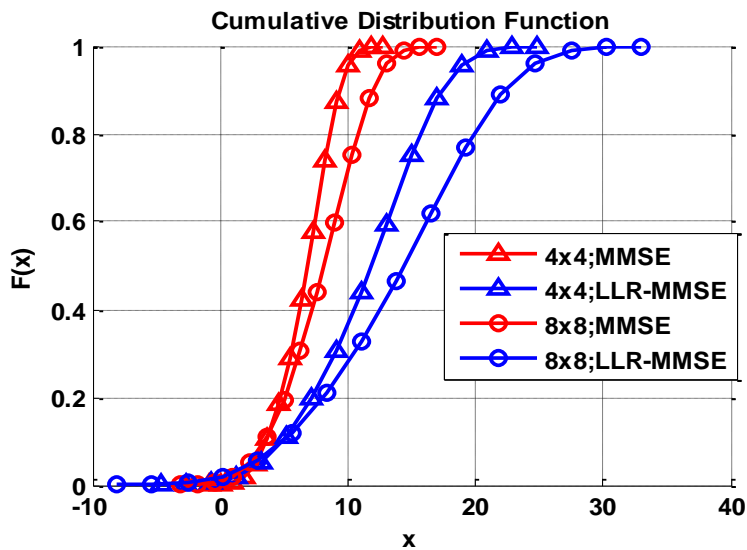


Fig.7. CDF of Channel Capacity with the Variation of Number of Antennas.

As indicated in the Fig. 7, with the increase in the number of antennas have significantly increase the channel capacity. But the main observation of the above figure is that the rate of increase of the capacity is different for the MMSE and LLR-MMSE receivers. If we consider $F(x)=0.9$ as reference level then the capacity gap for MMSE and LLR-MMSE receivers are 2.5 and 5 bps/Hz. It clearly indicate that LLR-MMSE receiver provide low complex receiver with improved system performance.

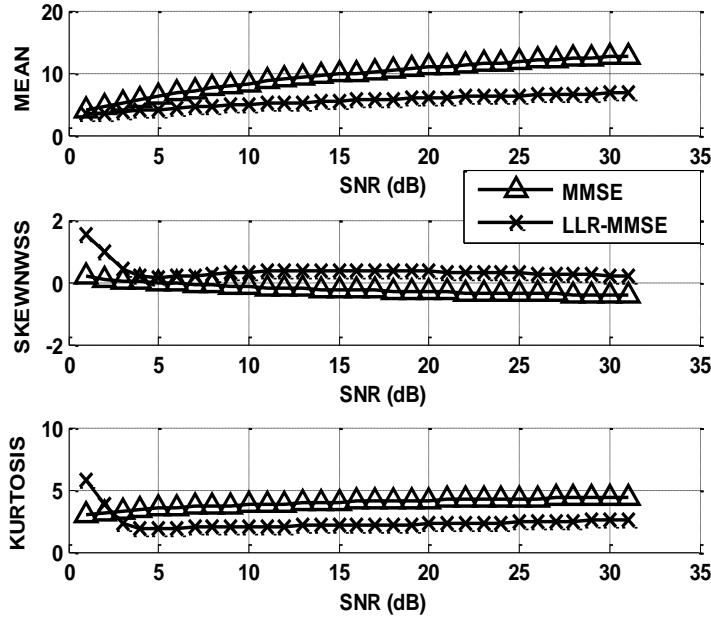


Fig.8. Mean, Skewness, and Kurtosis of the Capacity (bits/s/Hz) versus SNR for Nakagami-m (m=1) 2x2 MIMO Channels.

Fig. 8 shows the mean, variance, skewness, and kurtosis of MIMO channel capacity considering Nakagami-m channel. This represent a comparative higher order statistical analysis of the MIMO channel capacity in presence of the linear receiver MMSE and nonlinear low complex receiver LLR-MMSE. From the above result, one can conclude that LLR-MMSE receiver provide more stable receiver system.

4. Conclusions

In this paper, performance of different receiver system have been analyzed in Nakagami-m and SCM channel condition. Different channel condition have been taken into account to validate the utility of LLR based receiver for the MIMO system.

ZF and MMSE are most commonly used receivers for MIMO system. But with the increase in number of antennas, these algorithm need to be modified to reduce the computation complexity. LLR based receiver architecture produces low complex systems. LLR aided receiver boost the system performance significantly. Through the mathematical model and the simulation result we have demonstrated the effectiveness of LLR-MMSE receiver over the MMSE receiver.

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Samarendra Nath Sur: Born in Hooghly, West Bengal, India, in 1984. He received B.Sc degree in Physics (Hons.) from the University of Burdwan in 2007. He received M.Sc. degree in Electronics Science from Jadavpur University in 2007 and M.Tech degree in Digital Electronics and Advanced Communication from Sikkim Manipal University in 2012. He is currently working towards the Ph.D degree in Electronics and Communication Engineering at NIT, Durgapur.

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