Optimal Decoders for 4G LTE Communication

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Abstract—**Multiple Input Multiple Output (MIMO) techniques are used to realize practical high data rate systems which laid the foundation of Long Term Evolution (LTE). Various transmission techniques like Transmit Diversity (TxD), Open Loop Spatial Multiplexing (OLSM) and Closed Loop Spatial Multiplexing (CLSM) are deployed in the realm of MIMO. The spectral efficiency is improved with the help Orthogonal Frequency Division Multiplexing (OFDM). In this paper we will focus on CLSM, to evaluate its performance with the help of Zero Forcing (ZF), Minimum Mean Sqaure Error (MMSE), SoftSphere Decoder (SSD), SSD K-Best (SSDKB) and SIC receivers to find the optimal decoder in LTE environment. The SSD, SSD-KB and SIC uses MMSE based equalizers. The channel environment used are Additive White Gaussian (AWGN), Vehicular A (VehA), Vehicular B (VehB) and an outdoor Pedestrian (Ped B) channel model. A Least Square (LS) estimated feedback obtained by the averaging of two channel instances is used to improve BLER in the case of fading channels.**

Index Terms—**VehB, SSD, SIC, CLSM, LTE, LS.**

I. Introduction

Wireless communications continue to strive for higher data rates and a better link reliability in order to provide more advanced services on the go. The use of multiple antennas at both the transmitter and receiver side, i.e., *multiple-input multiple*-output (MIMO) communications, is one of the most promising technologies to fulfill these demands. Indeed, MIMO systems are capable of achieving increased data rates and an improved link reliability compared to single-antenna systems without the aid of additional bandwidth or transmit power. These improvements, however, require the use of more computationally intensive data detection algorithms at the receiver side. In particular, optimum data detection can easily become complex. Conventional sub-optimum detection techniques have a low computational cost but their performance is in general less significant to that of optimum data detection. Thus, there is a strong demand for computationally efficient data detection algorithms that are able to reduce this performance gap. One of the promising technologies to provide high data rate at high speeds while maintaining the specified Quality of Service (Qos) is Long Term Evolution (LTE). LTE provides a maximum downloading data rate of 299.6Mbits/s and an uploading data rate of 75.4Mbits/s constrained by the MIMO configuration and user speed. to facilitate higher data rate it provides a flexible spectrum management and supports allocation of multiple bandwidth slots to same user on demand. IT also supports multiple antenna configuration schemes from 4x4 MIMO to 1x1 SISO. different transmission schemes like multiplexing and transmit diversity to achieve high data rates nad provides aupport for users moving upto a speed of 500Km/hr (310 M/hr) depending upon the user terrain. Multiple decoding algorithms are available in LTE communication network to reduce the bit error probability. In this paper we mainly focus on Zero Forcing (ZF), Minimum Mean Sqaure Error (MMSE), SoftSphere Decoder (SSD), SSD K-Best (SSDKB) and SIC receivers to find the optimal decoder in LTE environment. The SSD, SSD-KB and SIC uses MMSE based equalizers. The channel environment used are Additive White Gaussian (AWGN), Vehicular A (VehA), Vehicular B (VehB) and an outdoor Pedestrian (Ped B) channel model. The simulation results achieved meet industrial standards with the help of link level LTE simulator [1] compliant with the parameters specified by the 3GPP working group. In the following paper Section II describes the channel model and receiver algorithm. In Section III, the CLSM mode of transmission is explained. The Section IV explains outcome of these simulations and observations. Conclusions are given in Section V.

II. Channel Model

The proposed MIMO [2] system model consisting of N_T transmit antennas and M_R receive antennas, defined by the following Equation (1).

$$\mathbf{y} = Hx + z \tag{1}$$

$$\mathbf{H}_{M_R,N_T} = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,N_T} \\ h_{2,1} & h_{1,2} & \cdots & h_{2,N_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{M_R,1} & h_{M_R,2} & \cdots & h_{M_R,N_T} \end{pmatrix} \tag{2}$$

where $y = [y_1 y_2 \cdots y_{M_R}]$ is the received vector, H is the channel coefficient matrix of the dimensions $M_R \times N_T$ defining the channel gain expected values and $z = [z_1 z_2 \cdots z_{M_R}]$ is the noise. **z** is assumed to be (i.i.d) Zero Mean Circularly Symmetric Complex

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Gaussian (ZMCSCG). The channel **H** is defined by the channel delay profile. The input is divided into different streams of data with the help of spatial demultiplexer as in Fig. 1. The streams are than processed by the turbo decoder to provide communication at low values of SNR. IFFT is used to provide computational efficiency and cyclic prefix is added to maintain synchronization.The streams are passed through the inter-leaver after the channel coding is applied. The inter-leaver processes the input such that the consecutive bits are placed far apart to avoid burst error due to fading. The modulation scheme is than applied which in this case is 16-QAM with an effective coding rate of 0.6016. The modulated data is passed through the serial to parallel converter. On reception data is processed with the decoder.

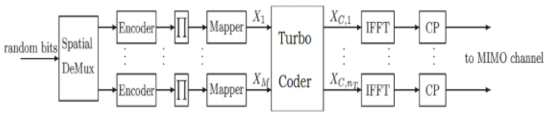


Figure 1. MIMO transmission scheme

Receiver Algorithm

A brief description of the receivers is given below:

ZF Receiver

Zero-Forcing (ZF) detection is the simplest and effective technique for retrieving multiple transmitted data streams at the receiver with very little complexity.

The probability density function (PDF) for the signal-to noise-plus-interference ratio (SINR) at the output of a zero forcing (ZF) detector in a flat fading channel was derived in [3], [4]. The zero-forcing (ZF) technique is used to nullify the interference with the help of following weight matrix:

$$W_{ZF} = \left(H^H H\right)^{-1} H^H \tag{3}$$

where $(.)^H$ denotes the Hermitian transpose operation. In other words, it inverts the effect of channel as

$$\begin{aligned}\tilde{x}_{ZF} &= W_{ZF}\, y; \\ &= x + \tilde{z}_{ZF}\end{aligned} \tag{4}$$

where $\tilde{z}_{ZF} = W_{ZF} z = \left(H^H H\right)^{-1} H^H z$. Note that the ZF error performance is directly proportional to the power of $\tilde{z}_{ZF}$. (i.e., $\left\|\tilde{z}_{ZF}\right\|_2^2$). The post-detection can be calculated using SVD as

$$\left\|\tilde{z}_{ZF}\right\|_2^2 = \left\|(H^H H)^{-1} H^H z\right\|^2 \tag{5}$$

$$= \left\|\left(V \textstyle\sum^2 V^H\right)^{-1} V \sum U^H z\right\|^2 \tag{6}$$

$$= \left\|V \textstyle\sum^{-1} U^H z\right\|^2 \tag{7}$$

Since $\left\|Qx\right\|^2 = x^H Q^H Q x = x^H x = \left\|x\right\|^2$ for a unitary matrix **Q**, the expected value of the noise power is given as

$$\begin{aligned} E\left\{\left\|\tilde{z}_{ZF}\right\|_2^2\right\} &= E\left\{\left\|\textstyle\sum^{-1} U^H z\right\|_2^2\right\} \\ &= E\left\{tr(\textstyle\sum^{-1} U^H z z^H U \sum^{-1})\right\} \\ &= tr(\textstyle\sum^{-1} U^H E\left\{z z^H\right\} U \sum^{-1}) \\ &= tr(\sigma_z^2 \textstyle\sum^{-1} U^H U \sum^{-1}) \\ &= \sigma_z^2 tr(\textstyle\sum^{-2}) \\ &= \displaystyle\sum_{i=1}^{N_T} \frac{\sigma_z^2}{\sigma_i^2} \end{aligned}$$

MMSE Receiver

Multiple antennas offer significant performance improvements in wireless communication systems by enabling communications by minimizing the error at higher data rates. Linear receivers like minimum-mean-squared-error (MMSE) receiver are a practical solution to provide lower complexity and higher data rates with the aid of multiplexing techniques which in our work is spatial multiplexing. The MMSE receiver is particularly important as it optimally trade off strengthening the energy of the desired signal of interest and canceling unwanted interference by using its receive degrees of freedom (DOF) such that the signal-to interference-and-noise ratio (SINR) is maximized. In [5], multiplexing at receiver side is used for spatial diversity to increase the desired signal power, while in [6], multiplexing at receiver side is used to cancel interference from the strongest interferer nodes. In [7], MMSE receivers are used and the average spectral efficiency, a per-link performance measure, was obtained in the large antenna regime. In [8 - 10], by using sub-optimal and MMSE linear receivers, the results of transmission capacity were shown to scale linearly with the number of receive antennas. The post-detection signal-to-interference plus noise ratio (SINR) can be maximized by using the MMSE criteria, the MMSE weight matrix is used which given as

$$W_{MMSE} = (H_H H + \sigma_z^2 I)^{-1} H^H \tag{8}$$

For MMSE receiver to perform efficiently, the statistical information of noise σ^2 is required. The ith row vector $w_{i,MMSE}$ of the weight matrix in Equation 8 is obtained by solving the optimization equation given below:

$$W_{i,MMSE} = \arg \min_{w=(w_1,\ldots,w_{N_T})} \frac{\left|wh_i\right|^2 E_x}{E_x \sum_{j=1, j\neq i}^{N_T} \left|wh_i\right|^2 + \left\|w\right\|^2 \sigma_z^2} \tag{9}$$

Using the MMSE weight in Equation 8, we obtain the following relationship:

$$\begin{aligned}\tilde{x}_{MMSE} &= W_{MMSE}\, y \\ &= (H^H + \sigma_z^2 I)^{-1} H^H z\end{aligned} \tag{10}$$

$$= \tilde{x} + \tilde{z}_{MMSE}$$

where $\tilde{z}_{MMSE} = ((H^H + \sigma_z^2 I)^{-1} H^H z)$. Using Singular Value Decomposition (SVD), the post detection noise power is given by the Equation 12.

$$E\{\|\tilde{z}_{MMSE}\|\} = E\left\{\left\|\left(\sum + \sigma^2 \sum^{-1}\right)^{-1} U^H z\right\|\right\}$$

$$= \sum_{i=1}^{N_T} \frac{\sigma_z^2 \sigma_i^2}{\left(\sigma_i^2 + \sigma_z^2\right)^2} \qquad (11)$$

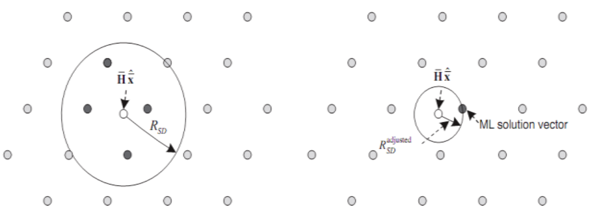
For a MMSE receiver it is preferable to have a high density of single-stream transmissions than a low density of multi-stream transmissions. This is because in MMSE detection, the interference powers from the strongest interferers source remaining after interference-cancellation are weaker for single stream transmission than multi-stream transmission.

Soft Sphere Decoder

SSD gives the ML solution with soft outputs. These ML symbols are chosen from a reduced set of vectors within the radius of a given sphere rather than a complete vector length. The radius of the sphere is adjusted such that there exists only one ML symbol within the given radius. SSD provides sub optimal ML solution [11] with reduced complexity provided MMSE is used to estimate the channel. The Soft Sphere Decoder (SSD) solution is given by the following equation.

$$arg\min_{x}\|y - Hx\| = arg\min_{x}(x - \hat{x})^T H^T H (x - \hat{x}) \quad (12)$$

where $(\cdot)^T$ denotes the transpose of matrix. Equation 12 gives the unconstrained solution of the real time system. This means that the ML solution can be determined by the term $(x - \hat{x})^T H^T H (x - \hat{x})$. No ML value exists outside the sphere because there ML value is greater than those which exists inide the sphere hence making a unique detection as in Fig. 2.



(a) Original sphere (b) New sphere with the reduced radius

Figure 2. Illustration of the sphere in sphere decoding.

K- Best Soft Sphere Decoder

The K-Best SSD is a variant of SSD, and performs its operation on K best selected optioins unlike the SSD which considers only one point.

Successive Interference Canceller Decoder

SIC receiver is a collection of linear receiver banks which successively cancels the interference which in this case are MMSE receivers, as shown in the Fig. 3.

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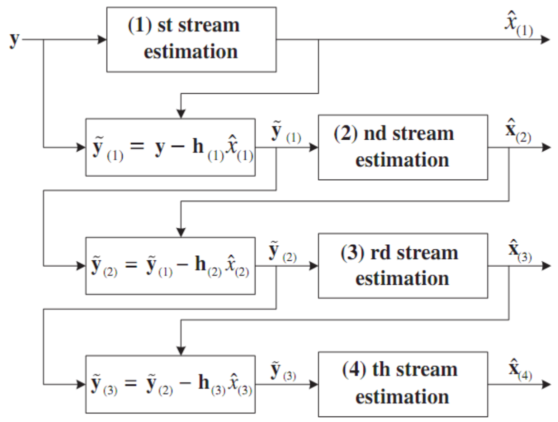

Figure 3. SIC receiver.

III. Transmission Models

MIMO improve the spatial and multiplexing gains by the use of diversity and spatial multiplexing [12]. The methods used to enhance the diversity and multiplexing gains is CLS

Closed Loop Spatial Multiplexing

Independent data streams are transmitted from the N_T transmit antennas in CLSM Fig. 4. In CLSM essential amount of CSI is used as feedback which enables us to achieve high throughput with lower BLER.

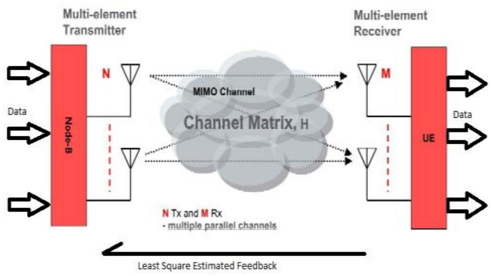

Figure 4. Block diagram of a MIMO transmission using CLSM.

IV. Simulation Results and Discussion

TABLE I. LTE Simulation Parameters.

Parameters	Values
Receivers	ZF, MMSE, SSD, SSDKB, SIC
Channel	Veh A, Veh B, PedB, AWGN
User Speed	30 Km/h, 120 Km/h and 3Km/h
Fading Type	Block Fading
Retransmission Algo.	HARQ
No of Retransmissions	03
Soft Demapper	Max Log Map
Modulation	16 QAM, CQI 9
Feedback Estimation	Least Square
Feedback Bits	01
Resource Blocks	06

In this paper, Hybrid Automatic Repeat Request (HARQ) is set to a maximum value of 03 to provide retransmission in the case of fading i.e. block fading in this scenario. Soft decisions are made using the max log map criterion for lower probability of error. VehA and VehB channels are considered for observing the LTE link behavior. The feedback for supporting CLSM transmission mode is obtained by channel averaging of two channel realizations. A complete detail of the parameters used in the simulations are given by the Table I.

In case of AWGN channel, from Fig. 5 and 6 it can be seen that at higher values of SNR all the receivers are performing equally good giving almost the same throughput and BLER. In case of lower SNR, in AWGN channel SIC receiver gives a better output as compared to all other receivers.

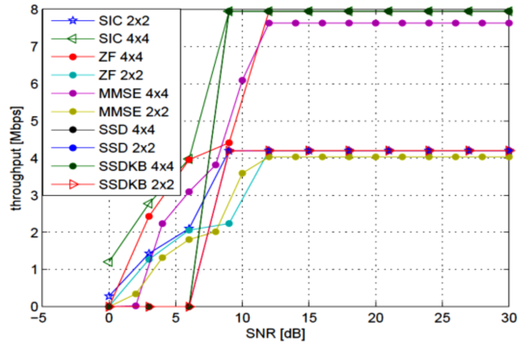

Figure 5. Receivers throughput in AWGN channel using CLSM.

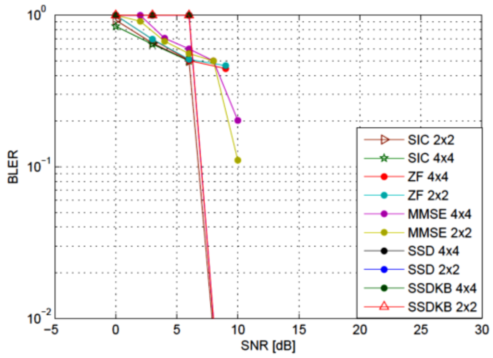

Figure 6. Receivers BLER in AWGN channel using CLSM.

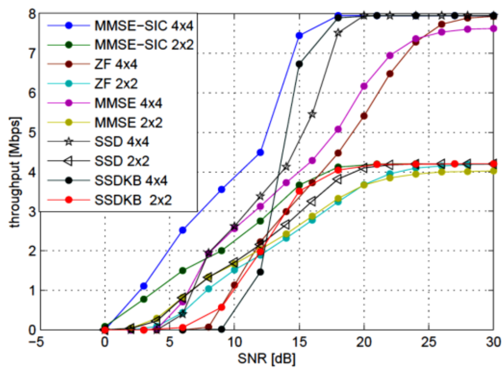

Figure 7. Receiver's throughput in VehA channel using CLSM.

In case of VehA channel, from Fig. 7 & 8 it can be seen that at higher values of SNR, SIC receiver is giving the best out put in terms of throughput and BLER while SSD-KB is providing a sub optimal output.

For the lower values of SNR, SIC is the best performer among all the receivers while SSD is the second best. In case of VehB channel, from Fig. 9 and 10 it can be seen that at higher values of SNR, SIC receiver is the best performer in terms of throughput and BLER while SSD-KB is providing a sub optimal output.

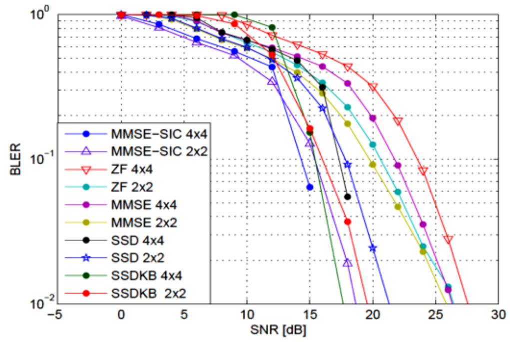

Figure 8. Receivers BLER in VehA channel using CLSM.

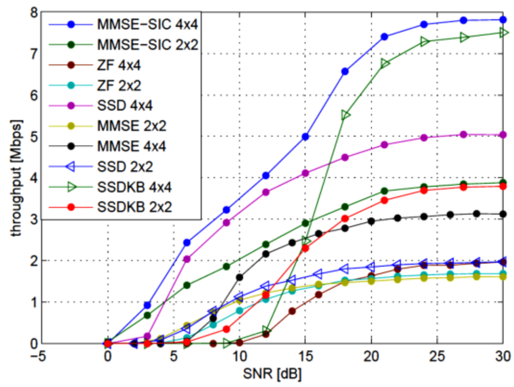

Figure 9. Receivers throughput in VehB channel using CLSM.

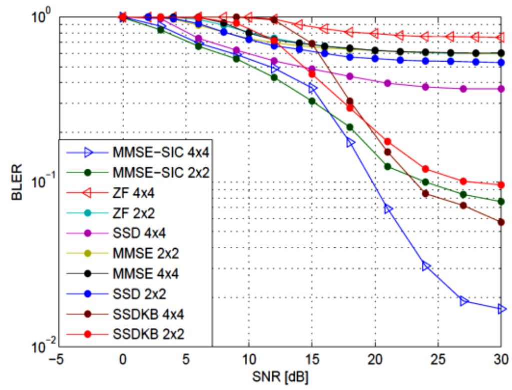

Figure 10. Receivers BLER in VehB channel using CLSM.

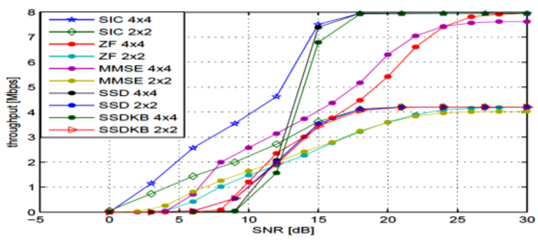

Figure 11. Receivers throughput in PedB channel using CLSM.

For the lower values of SNR, SIC is the best performer among all the receivers while SSD is the second best.The BLER in this case is worst among all the channel conditions and the reception of correct data is hardly expected. In case of outdoor pedestrian channel model Ped B, from Fig. 11 and 12 the performance of SIC is no different as in the case of VehA and VehB channel. SSD and SSDKB performs almost same at the higher values of SNR. At the lower values of SNR, the 2x2 version of SIC receiver is performing better than the 4x4 versions of SSD, SSDKB , MMSE and ZF receivers in terms of throughput and SNR.

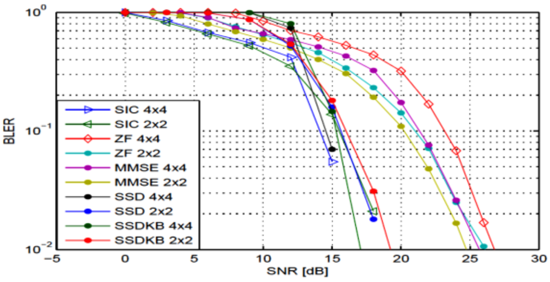

Figure 12. Receivers BLER in PedB channel using CLSM.

V. CONCLUSIONS

In order to achieve higher through put [13] in LTE, SIC receiver must be used in all channel models. Considering the performance/complexity trade off SSD and SSDKB receivers provide a reasonable output in terms of throughput and BLER as compared with the SIC receiver. This performance/complexity trade-off makes SSD and and its variant SSDKB as the optimal receivers. A carefully designed mechanism is needed to select the optimal receiver according to the throughput and BLER requirements of the user keeping in view the performance/complexity trade-off in case of both high and low values of SNR. There is a great room for improvement in terms of throughput and BLER with the help of CLSM. This can be improved by increasing the number of pilot channels or by increasing the number of bits per pilot channel providing the feedback while conserving the communication standards specified by the 3GPP and ITU-T to get the advantages of CLSM.

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