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Performance Analysis of MIMO Detection Algorithms with BPSK and PAM Modulation

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***Abstract:** One of the best strategies for worthwhile Communication in wireless technologies is MIMO i.e., Multiple input and Multiple output systems where the information exchange is happened through multiple antennas. The Wireless transmission of data/signal suffers from fading and interference effects which creates a problem for signal recovery in wireless communication hence these effects can be controlled by the equalizer. The MIMO system uses multiple antennas at the transmitter and receiver to exploit multipath propagation. The paper emphasizes various channel equalization algorithms recognized for sub-optimum MIMO detection which include Zero Forcing (ZF), Minimum Mean Square Error (MMSE), ZF-SIC, and MMSE-SIC equalizers, the performance is evaluated for 2*2 and 4*4 MIMO wireless channels using various modulation schemes in which BER is taken for consideration. The implementation work is carried out through MATLAB toolbox version 2018b.*

***Index terms:** BER, ZF Equalizer, MMSE Equalizer, ZF-SIC Equalizer, MMSE-SIC Equalizer.*

I. INTRODUCTION

Multiple Input Multiple Output (MIMO) [4], a wireless technology employing multiple antennas to transmit and receive multiple parallel signals figuring out for a higher data rate in contrast to systems of a single antenna, where these antennas are pointed at both ends of the communication circuit, meant for error reduction and optimizing data speed. The MIMO technology wraps the signal or data in the same bandwidth range because of which the system throughputs a better signal strength. The presence of multiple data streams leads to better signal quality to and fro through different paths which dig out in a significant reduction in the loss of data packets. From the theoretical study, it is clear that the MIMO transmitting antenna transmits various signals from all the elements at once which in turn make the receiver solve a linear equation for demodulating the message, ultimately achieving high data rate communication irrespective of mobility and location. The transmission of data at very high data rates is highly demanded, offering services like not limited to FHD video streaming, broadcasting top-quality audio, but also various applications under mobile integrated services, and digital network services through mobile radio channels is crucial in the mobile communication systems. During this transmission of data, the channel impulse response can spread over and across many symbol periods, driving for inter-symbol interference (ISI) which is compensated by equalizers. Channel estimation monitors and provides the information about any distorted transmitted signals while the signal propagates through the channel, soon which the information is taken by the equalizers to reduce and remove the co-channel interference caused by fading. Hence the transmitted signal gets restored. The channel estimation which aims at delivering the simple and best performance can be scrutinized by various algorithms [3] and techniques for improving the network reliability with no loss in data. This paper interprets and discusses the performances of ZF, MMSE, ZF-SIC, and MMSE-SIC channel equalization techniques by assessing 2×2 MIMO, 4x4 MIMO transmitting and receiving antennas accounted for BPSK and PAM modulation schemes.

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II. LITERATURE REVIEW

As technology is advancing day by day, unique algorithms [6] are getting explored and are answerable for more acceptable performances of the communication channels for which the best specimen is the OFDM, and MIMO technologies in 4G and 5G evolutions. In [1] the performance of BER Versus SNR is evaluated between ZF equalizer receiver and MMSE equalizer receiver for 2*2 MIMO and 4*4 MIMO with BPSK modulation figured that MMSE is a better performer than ZF receiver as it fails to detect signals because of its constraints; primarily, ZF is considered to be a good receiver under noise-free conditions only, Secondly, the channel may consist of zeros in its frequency response but that cannot be reversed, in addition the channel impulse response has a finite length but due to finite length, it does not fulfill all conditions. In [2] the performance of BER Versus SNR is interpreted between ZF equalizer, ZF-SIC equalizer, MMSE equalizer, and MMSE-SIC equalizer receivers for 2*2 MIMO and 4*4 MIMO with BPSK modulation and QAM modulation and exhibited that a reasonable reduction of BER is achieved by MMSE-SIC and ZF-SIC algorithm which has more scope of advancement in terms of performance The present work competed in evaluating the performances of ZF, ZF-SIC, MMSE, and MMSE-SIC equalizers on different MIMO systems with available modulation techniques i.e., BPSK and PAM, and illustrates that the MMSE-SIC receiver algorithm performance is more pleasing compared to others; irrespective of modulation technique and the number of transmitters and receivers utilized.

MMSE-SIC perform best in all scenarios and also has low SER compared to other algorithms, as it possesses low BER/SER which will be highly demanded in forthcoming technologies.

III. SYSTEM MODEL

A MIMO with multiple antennas at transmitter and receiver usually correlates to higher speeds as the data rate increases by a factor relying on the number of transmitting and receiving antennas. In spite MIMO also takes the edge to increase the receiver signal-capturing power, link reliability, performance, and receiving diversity. Multipath is one of the parts of a MIMO technology that focuses on radio wave phenomena. The generalized block diagram of circuit is depicted in figure1.

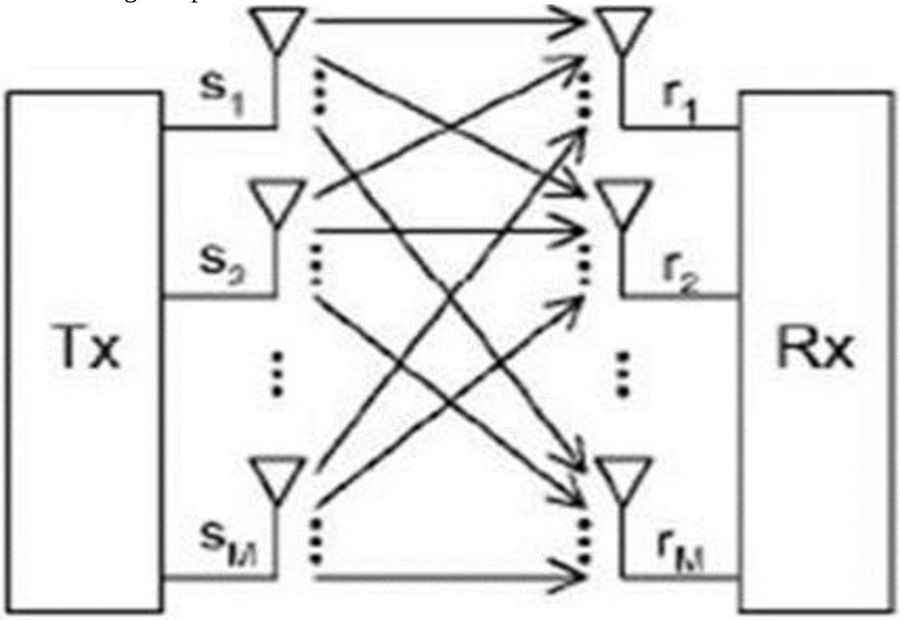

Figure 1: MIMO Antenna Communication System

For Consideration let's have a 2*2 MIMO system and the computation involved for increases in its data rate by a factoris shown below

- Consider that we have a transmission sequence, for example {x1, x2, x3 ... xn}.
- In normal transmission, we will be sending *x*1 in the first time slot, *x*2 in the second time slot, *x*3, and so on.
- However, as we have 2 transmit antennas, we may group the symbols into groups of two {x1, x3, x5 ....}, {x2, x4, x6 ….} such that in the first time slot, we send *x*1 and *x*2 through each antenna. In the subsequent time slots, *x*3 and *x*4, *x*5 and *x*6 and so on.
- As we are grouping two symbols and sending them in the single-time slot, which endures 'n/2' time slots to complete the transmission instead of 'n'. Hence the data rate is doubled.

Courteously, the MIMO transmission scheme data rate will be doubled for N*N MIMO system.

A.Zero forcing equalizer.

Zero Forcing equalizer is a kind of graphical equalization algorithm that is widely used in communication systems which applies inversely to the received signal so that it can restore the signal [2]. By applying the ZF equalizer technique it is possible to put down the value of Inter Symbol Interference (ISI) at zero for a noise-free channel. This will be useful when ISI is significant compared to noise.

The Zero Forcing Equalizer C(f) is represented by

$$C(f) = 1/F(f)$$

where f is a channel frequency response.

The combination of channel and equalizer presents a flat frequency response and linear phase F(f)C(f) = 1.

Consider the MIMO channel

$$Y = HX+N \quad \text{……………} \ (1)$$

Where, Y = Received symbol matrix

H = Channel matrix

X = Transmitted symbol matrix

N = Noise matrix

Consider a 2*2 MIMO system,

The received signal on the first receive antenna is

$$y_1 = h_{11}x_1 + h_{12}x_2 + n_1 \quad \text{………..} \ (2)$$

$$y_1 = [h_{11} \quad h_{12}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \quad \text{……...} \ (3)$$

The received signal on the second receive antenna is

$$y_2 = h_{21}x_1 + h_{22}x_2 + n_2 \quad \text{……….} \ (4)$$

$$y_2 = [h_{21} \quad h_{22}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \quad \text{………} \ (5)$$

where

y1, y2 are the received symbol on the first and second antenna respectively,

h1,1 is the channel from 1st transmit antenna to 1st receive antenna,

h1,2 is the channel from 2nd transmit antenna to 1st receive antenna,

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h2,1 is the channel from 1st transmit antenna to 2nd receive antenna,

h2,2 is the channel from 2nd transmit antenna to 2nd receive antenna, x1, x2 are the transmitted symbols and

n1, n2 is the noise on 1st, 2nd receive antennas

The equation can be represented in matrix notation as follows:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad \ldots\ldots\ldots\ldots \quad (6)$$

The flowchart for Zero Forcing Equalizer is shown in figure2

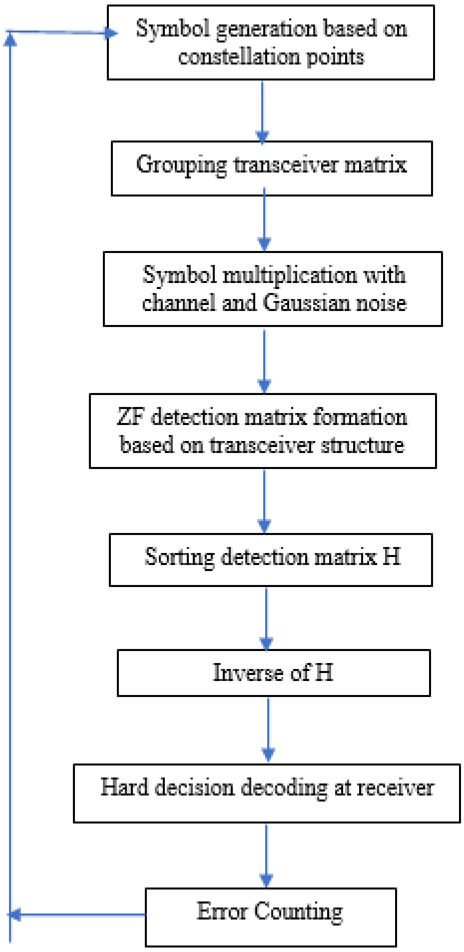

Figure 2: Flowchart for ZF Equalizer

The Zero Forcing (ZF) detector for meeting this constraint is given by,

$$W = (H^H H)^{-1} H^H \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where

W - Equalization Matrix,

H - Channel Matrix.

This matrix is known as the Pseudo inverse for a general m x n matrix where

$$H^H \mathrm{H} = \begin{bmatrix} h_{11}^* & h_{21}^* \\ h_{12}^* & h_{22}^* \end{bmatrix} \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$$

$$= \begin{bmatrix} |h_{11}|^2 + |h_{21}|^2 & h_{11}^* h_{12} + h_{21}^* h_{22} \\ h_{12}^* h_{11} + h_{22}^* h_{21} & |h_{12}|^2 + |h_{22}|^2 \end{bmatrix} \ldots \ (8)$$

B. BER with ZF equalizer for 2*2 and 4*4 MIMO

The Zero forcing equalizer attempt to null out the interference terms when equalization is carried out. If the channel response (or channel transfer function) for a particular channel is H(s) then the input signal is multiplied by the reciprocal of it. This is intended to remove the effect of channel from the received signal, in particular the inter symbol interference (ISI).

The zero-forcing equalizer removes all ISI, and is ideal when the channel is noiseless. However, when the channel is noisy, the zero-forcing equalizer will amplify the noise greatly. Hence ZF equalizer is not the possible equalizer for equalization process but however it is simple and easy to implement.

The bit error rate for 2*2 MIMO and 4*4 MIMO can be calculated from the following equation

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{E_b}{N_o}}{1+\frac{E_b}{N_o}}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \ (9)$$

Where

P_b is bit error rate

$\frac{E_b}{N_o}$ is signal to noise ratio

C. Minimum Mean Square Error equalizer

A more balanced linear equalizer in this case is the minimum mean-square error equalizer[4], that calculates the Mean Square Error (MSE) and tries to minimize the error. The main property of MMSE is that it does not usually eliminate ISI completely but instead minimizes the total power of the noise and ISI components in the output. Let x be an unknown random variable, and let y be a known random variable. An estimator x^(y) is any function of the measurement y, and its mean square error is given by,

$$\mathrm{MSE} = E[(X\,\hat{}\,X^2)] \quad \ldots\ldots\ldots\ldots \ (10)$$

The expectation is taken over both x and y.

Since it is a linear estimator by following the term AY + b we acquire a minimum MSE where measurement Y is a random vector, A is a matrix and b is a vector.

D. Minimum Mean Square Error Equalizer for 2*2 MIMO.

The Minimum Mean Square Error **(**MMSE**)** approach tries to find a coefficient *W* which minimizes the criterion

$$E[(W_{y-x})(W_{y-x})H]$$

Where

- ✓ W is Equalization matrix
- ✓ H is channel matrix
- ✓ y is received signal
- ✓ x is transmitted signal

Flow chart for MMSE equalizer is as shown in figure 3;

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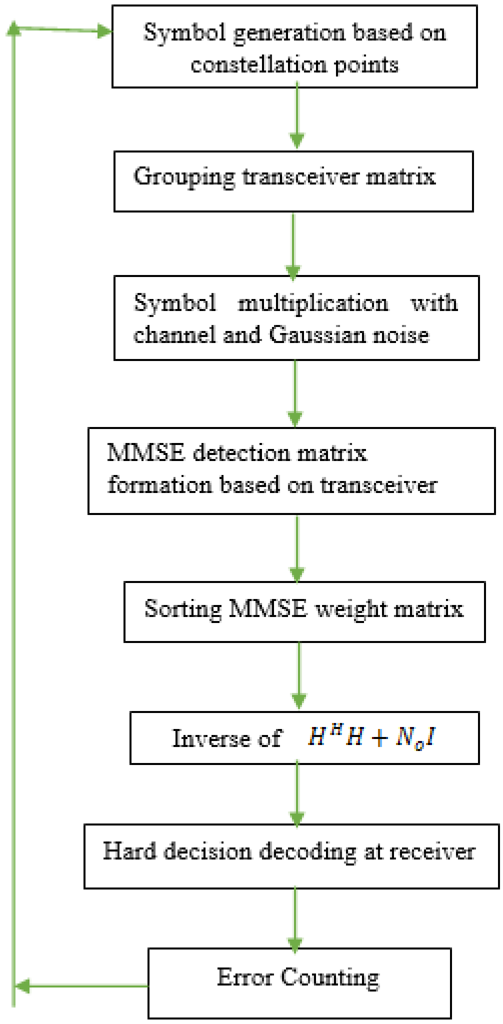

Figue3: Flowchart for MMSE Equalizer

To solve for transmitted signal, we need to find a matrix W which satisfies WH = I. The Minimum Mean Square Error (MMSE) detector for meeting this constraint is given by,

$$W = [H^H H + N_o I]^{-1} H_H \quad \text{.................. (11)}$$

This matrix is known as the Pseudo inverse for a general m x n matrix where

$$H^H H = \begin{bmatrix} h_{11}^* & h_{21}^* \\ h_{12}^* & h_{22}^* \end{bmatrix} \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$$

$$= \begin{bmatrix} |h_{11}|^2 + |h_{21}|^2 & h_{11}^* h_{12} + h_{21}^* h_{22} \\ h_{12}^* h_{11} + h_{22}^* h_{21} & |h_{12}|^2 + |h_{22}|^2 \end{bmatrix} \text{...(12)}$$

When comparing two equations i.e. eq. (11) and eq. (7) in Zero Forcing Equalizer, we see that both equations are comparable except $N_O I$. Indeed, when the value of the noise term is zero the MMSE equalizer minimizes to Zero Forcing equalizer.

E. ZF-SIC & MMSE-SIC Detectors

The performance of SIC detectors is better than the ZF and MMSE detectors. The SIC detectors [7] opt for a two-step iterative process: first a decision is taken on the first position X1 and then assuming that the decision was right, the detector corrects Y by removing the interference that would have been generated by X1. then SIC detectors repeat this process on the next X's entry until the whole vector is received.

Steps in Zero Forcing with SIC Algorithm are as follows

Step1: Ordering

To determine the transmitted stream with lowest error variance.

Step2: Interference Nulling

Estimation of the strongest transmitted signal by Nulling out all weaker signals.

Step 3: Interference cancellation

Demodulate the data bits, subtract their contribution from the received signal vector and return to the ordering step.

Steps in MMSE with SIC algorithm are as follows

Step 1: MMSE detection

Step 2: Information of input vector based on the received signal on each dimension

Step 3: Sorting the group vector from input vector.

Step 4: Removal of noise as well as ISI effect based on group vector in order.

Step 5: Best possible group vector selection according to SNR

Step 6: Hard decision decoding at receiver

Step 7: Error counting.

IV. SIMULATION RESULTS

Equalizers are mostly used in the detection of MIMO signals and their performance concerning symbol error rate and signal-to-noise ratio [5].

Here Considered MIMO system configurations of 2*2 and 4*4 using BPSK [8] and PAM modulation techniques for 1000 iterations. The Performance evaluations of the same are figured in 4, 5, 6, 7.

A Table 1 of comparison is picturized wrapping various modulation schemes entitled for each and every equalizer for SER in the range of 0.1 to 1.0, it is noticed that the MMSE-SIC equalizer or MIMO detector [9] are satisfactory compared to other detection algorithms and also, it is to be eyed that the value of SNR increases in accordance with SER decrease. Due to the addition of successive interface cancellations the performance of thedetector is improved and hence MMSE is spotted as better performer then ZF detector In addition to these, it is inferred that 2*2 and 4*4 MIMO using PAM modulation, MMSE-SIC is performing better compared to other detection algorithms

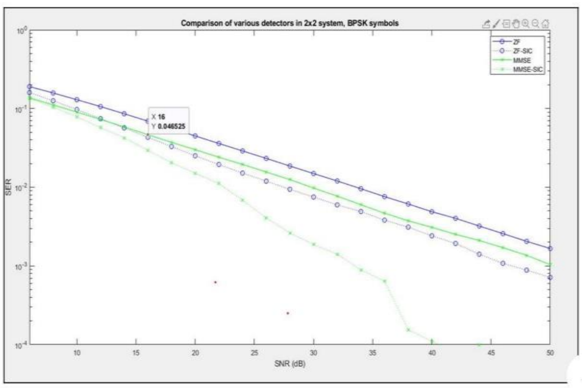

Figure 4: Detectors in 2*2 MIMO system using BPSK symbols

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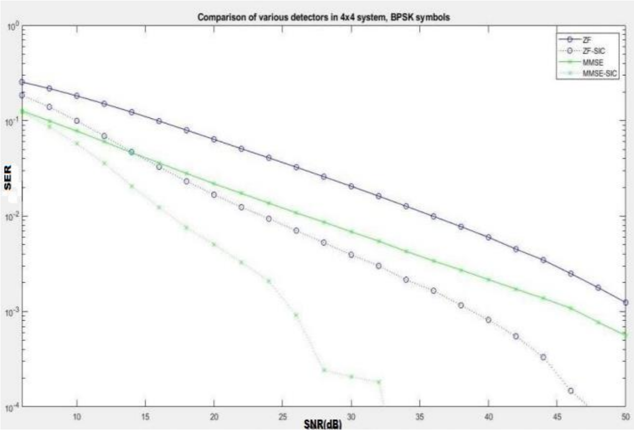

Figure 5: Detectors in 4*4 MIMO system using BPSK symbols

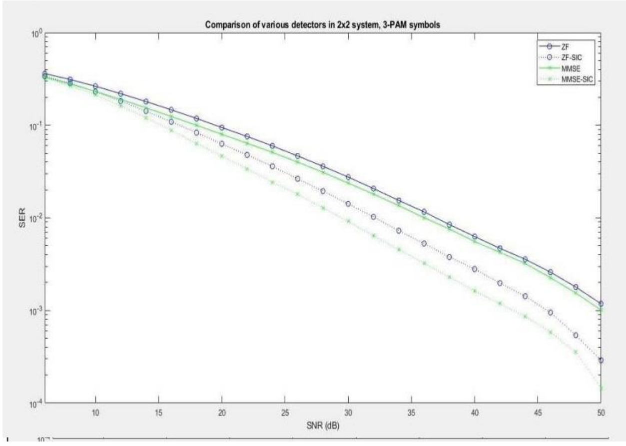

Figure 6: Detectors in 2*2 MIMO system using PAM symbols

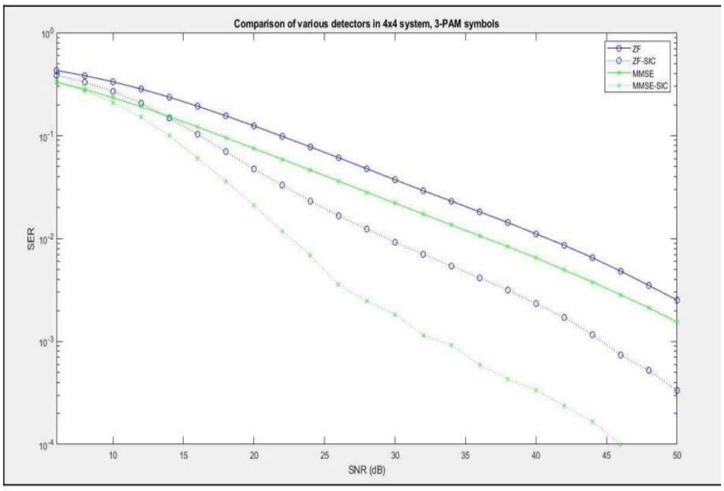

Figure 7: Detectors in 4*4 MIMO system using PAM symbols

Table 1: Comparison Table of Various Equalizers with Different Modulation Schemes

Equalizers	Modulation Technique			
	BPSK		*PAM*	
	2X2 MIMO	4X4 MIMO	2X2 MIMO	4X4 MIMO
Zero-Forcing (ZF)	>54dB	>56dB	>56dB	>56dB
Minimum Mean Square Error (MMSE)	>53dB	>52dB	>55dB	>54dB
Zero Forcing-Successive Interference Cancellation (ZF-SIC)	>52dB	=47dB	>53dB	>52dB
Minimum Mean Square Error Successive Interference Cancellation (MMSE-SIC)	=40dB	=33dB	>51dB	=46dB

V. CONCLUSION

The MMSE-SIC detection algorithm performance is better compared to detection algorithms like ZF detector, MMSE detector and ZF-SIC detector and this algorithm gives better performance irrespective of modulation technique that is used and also number of transmitters and numbers receivers used. From the simulation results it is concluded that MMSE-SIC performs best in all scenarios and also has low SER compared to other algorithms. Since it has low SER this MMSE-SIC algorithm can be used in 5G communications for detection of massive MIMO signals.

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