International Journal of Grid and Distributed Computing
Vol. 13, No. 2, (2020), pp. 2598-2608

Performance analysis of MIMO System capacity with various Receiver Architectures

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Abstract

Progress is aspired by the present-day technologies. Due to such progressions various researches are performed in substantial improvement areas. In the wireless spectrum, end-users 'amount is increasing day by day that leads to the requirement of enhanced BER values and bandwidth usage. Furthermore, in these modern times, new technologies are proved as research's crucial point that increases the wireless systems' capacities. A comparison of their BER performance charts is used to evaluate different combinations of multiple user receivers for determining performance under normal working conditions. In order to use the increased capacity rates, which can be achieved using a MIMO (multiple input and multiple output) configuration, MIMO systems are combined into system. MIMO with technology's complete dissemination through key attributes and components' investigation regarding single user communications. Various MIMO receivers' BER (Bit Error Rate) performance is also investigated. Adding SIC (Successive Interference Cancellation) to the MMSE (Minimum Mean square error) as well as ZF (Zero Forcing) MIMO receiver gives some changes to enhancements of BER value, but such minor change is important while ordering is performed with SIC. This particular paper provides a typical MIMO system. Compared to above-developed user systems, modern systems adopt a multi-user scenario. The present requirement for higher data rates resulted in the various techniques use like OFDM by the industry and the additional use of MIMO capabilities in WIFI (Wireless fidelity) s and CDMA (Code Division Multiple Access).

Keywords- *Successive Interference Cancellation (SIC), Minimum Mean square error (MMSE) Zero Forcing (ZF).*

1. Introduction

The word "MIMO" is utilized to characterize system which utilize many antennas both at transmitters and at receivers to boost efficiency with the achievement of increased BERs. Smart antennas are used by this technology [1]. This is considered as the key innovations in wireless networking infrastructure of the third century and is studied globally. The signals are distributed over many pathways such that spatial variation is imposed on the data stream of the system. It is doubtful that all tracks will suffer from extreme fading, allowing the MIMO system to boost signal obligations in a wireless natural world. MIMO networks have been desirable developments in WiMAX (IEEE 802.16), WCDMA and, wireless LAN (IEEE 802.11n). This has been primarily because of the large improvement in data link range and data throughput, without either requiring increasing system bandwidth or transmitting power.

2. Implementation

The various transmission antennas on the transmitter relay separate sources of the data into the tube. The streams transmitted are assisted by a transmission channel consisting of a matrix representation created by several antennas at both transmitting as well as receiving ends [2]. Many signal vectors obtained to retrieve the data stream are decoded by the receiver. Depending on the design purpose in question, the MIMO system's total performance as well as capability are described. MIMO systems are usually used for one or more of the following strategies, depending on the appropriate scenario.

2.1 MIMO Transmitter

2.1.1 MIMO with Pre-Coding

For modifying the beam forming [3] for supporting MIMO multi-layer transmissions pre-coding method is utilized. Beam shaping is a mechanism in which each antenna transmits the same signal with the correct weighting of the corresponding power and stage to optimize the signal power at the recipient antenna. Factors such as line of sight and location influence this particular setting and therefore it must be tailored to the MIMO scenario. Multiple antennas are possessed by MIMO receivers so that single layer beam formation at all the receiving antennas is not adequate to simultaneously achieve maximum received signal levels. This is achieved by pre-coding for this multilayer level configuration layout of the MIMO to improve overall system performance. In such system in which pre-coding is utilized, multiple streams with separate weighting per antenna of the intended transmission signal(s) are modulated to the source. This would improve the necessary data efficiency in the processing of the receiver. It necessitates earlier information on the state of channel, and CSI must be used effectively on the transmitter.

2.1.2 MIMO with Spatial Multiplexing

Normally, a signal with higher data rate is distributed by separating it into many low-rate data sources. In the same frequency band, each current is then transmitted from another antenna. At the source, the flux is divided into parallel channels, providing distinct spatial signatures arrive at the source antenna. With or without CSI information, this multiplexing approach can be applied.

2.1.3 MIMO with Diversity Coding

Diversity coding strategies are used to improve device efficiency in a standard MIMO communication situation in which the CSI is not identified. A single stream from each antenna is transmitted using different coding methods, for example space-time coding that uses selective or complete orthogonal coding. According to modern wireless communication networks, a route from sender to receiver via a viewing line is typically not very simple, thus diverse systems use the means to make the best possible approximation for the transmitted stream of the various paths generated by the transmitted signal's interaction with the atmosphere (that are mountains, tree, buildings and so on) Space time encryption is used to use the signal received at the source. Owing to the multi-path situation, the signal transmitted typically undergoes multiple degradations, time delays, and phase changes because of scenarios of multi-path. At the source, no CSI expertise is required. There are various diversity coding systems, but the final selection of the scheme, or MIMO implementation, typically relies on device specifications. Figure1 gives an example of a MIMO uplink device.

For evaluating the MIMO systems, its associated signals' linear representation is needed. Supposing a system which comprising of M receive as well as N transmit antenna, in which n_n represents the noise, h_{mn} represents the channel matrix, H's related entry and x_n presents the transmitted signal; therefore, y_m received signal is presented as:

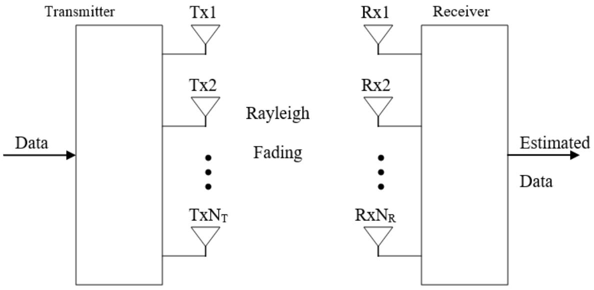

Figure1: A Standard MIMO System

$$y_m = \sum_{n=1}^{N} h_{mn} x_n + n_n \qquad \text{m} = 1,2,\ldots\text{M} \tag{1}$$

The multiple receives and transmit antennas produce coefficients of channel which are comprehended in an M x N channel matrix form represented as.

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N} \\ h_{21} & h_{22} & \cdots & h_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MN} \end{bmatrix} \tag{2}$$

Thus; the received signal at any given time, t, is stated as:

$$y(t) = Hx(t) + n(t) \tag{3}$$

Where, noise is presented by *n(t)* with σ^2 variance. MIMO systems’ advantages can be understood by its throughput that is capacity of MIMO system.

2.2 MIMO System Capacity

[3] is included with derived as well as documented MIMO capacities equations. Various assumptions are included for deriving these equations that are:

- During the data burst there exists narrowband Rayleigh channel
- Irrespective of the transmit antennas’ number total transmitted power and additive white Gaussian noise found to be constant
- Receiver channel knowledge.

As per the abovementioned assumptions; following equations are utilized for calculating the overall channel capacity is given [4], [5], [6], [7].

$$C = \log_2 \det\left[I_m + (\rho/n) HH^H\right] \text{ b/s/Hz} \tag{4}$$

$$C = \log_2 \det\left[I_m + \frac{\rho}{n} R\right] \text{b/s/Hz} \tag{5}$$

Where, *R* presents the normalized channel correlation matrix, ρ presents the average SNR exhibited at every receiving antenna, I_m presents an identity matrix, and *C* presents capacity of system.A “water filling” algorithm

$$C = \sum_{1}^{k} \log_2 \det\left[1 + \frac{\rho}{n} \lambda_i\right] \text{ b/s/Hz}$$

em capacities [4], [7] by utilizing

the single value decomposition theory [7]. It resulted in famous equation as given:

(6)

Where, k represented the matrix rank as well as λ_i represents the HH^H matrix's i^{th} eigen mode.Such equations allow a MIMO channel's visualization to be parallel SISO, *single-input single-output*, pipes that possesses the gains equivalent to their eigenvalues respectively. Thus, in case of transmitter known channels, for increasing their capacities only "**good channels**" are used that means those channels under an unequal power distribution exhibits greatest gain. Because of this (7) is transformed from (6) as:

$$C = \sum_{1}^{k} \log_2 \det\left[1 + \frac{p_i}{\sigma^2}\lambda_i\right] \text{ b/s/Hz} \tag{7}$$

Where, p_i represents the i^{th} pipe power.

The water-filling method previously described can be used to quantify this amount. The functionality of a single MIMO user system varies from multi-user applications.

2.3 MIMO Detectors

Few detectors are possible but most are non-linear and/or linear detectors' combinations. VBLAST, OSIC, MMSE and ZF devices are the primary detectors. New technology like Sphere Detectors have arisen that have Bit Error Rate with lower device complexity similar to ML approximation. These detectors are measured using various modulation and antenna setups. There are several different MIMO setups, but the approach followed and the observations taken in this study are seen as.

2.3.1 Zero Forcing (ZF) Detector

It is among the easiest available algorithm. This acts like a regular equalizer as the opposite of output of the frequency of channel is used in the received signal. In principle, such effective, however this is very susceptible for noise in realistic conditions since the opposite of the noise received to the signal is also true, as the response of channel involves a noise (3). Thus, for unnoisable signals, the ZF algorithm proves to be very successful, because ISI (Inter-Symbol Interference) can be removed through it but not suitable for a noisy signal because receiver's noise is increased by it [8].

Clearly, channel knowledge is important to use this algorithm on the receiver that enhances the system's complexity. The calculation, y of the obtained signal can therefore be written in respect of MIMO systems as:

$$\bar{y}_{ZF} = (H^H H)^{-1} H^H y = H^+ y \tag{8}$$

Where Moore-Penrose inverse is represented by H^+ that effectively is H matrix's pseudo-inverse.

Further analysis of the MIMO mechanism is possible (3). The data received by the two recipients was precisely generated by signals from both transmitter antennas. The obtained data from the first slot are y1 and y2, where antennas are collected

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 \quad ; \qquad y_1 = [h_{1,1}, h_{1,2}]\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + n_1 \tag{9}$$

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 ; \qquad y_2 = [h_{2,1}, h_{2,2}]\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + n_2 \tag{10}$$

$$y = y_1 + y_2$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{11}$$

x_1: First antenna’s transmitted symbol
x_2: Second antenna’s transmitted symbol
y_1: First transmitter’s evident received signal
y_2: Second transmitter’s evident received signal
$h_{1,1}$: Channel to first receive antenna from first transmitting antenna
$h_{1,2}$: Channel to first receiving antenna from second transmitting antenna
$h_{2,1}$: Channel to second receiving antenna from first transmitting antenna
$h_{2,2}$: Channel to second receiving antenna from second transmitting antenna
n_1: First receiver noticed noise
n_2: Second receiver noticed noise

The (11) H matrix represents the matrix and H^+ its corresponding matrix is presented in (12).

$$H^+ = (H^H H)^{-1} H^H = \begin{bmatrix} \bar{h}_{1,1} & \bar{h}_{2,1} \\ \bar{h}_{1,2} & \bar{h}_{2,2} \end{bmatrix} \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \tag{12}$$

$$H^+ = \begin{bmatrix} h_{1,1}{}^2 + h_{2,1}{}^2 & \bar{h}_{1,1} h_{1,2} + \bar{h}_{2,1} h_{2,2} \\ \bar{h}_{1,2} h_{1,1} + \bar{h}_{2,2} h_{2,1} & h_{1,2}{}^2 + h_{2,2}{}^2 \end{bmatrix}^{-1} H^H$$

For higher antenna configuration adjustment of the solution means more work as well as makes the system more complex. For example, solving the opposite matrix of a 4x4 MIMA system where a similar procedure as the above can be shown below.

$$\text{For } H = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} & h_{1,4} \\ h_{2,1} & h_{2,2} & h_{2,3} & h_{2,4} \\ h_{3,1} & h_{3,2} & h_{3,3} & h_{3,4} \\ h_{4,1} & h_{4,2} & h_{4,3} & h_{4,4} \end{bmatrix} \tag{13}$$

Because of four receive antennas’ presence, receiver receives antenna signatures of four distinct types shown as

$$y_3 = [h_{3,1}\ h_{3,2}\ h_{3,3}\ h_{3,4}] \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} + n_3 \qquad y_4 = [h_{4,1}\ h_{4,2}\ h_{4,3}\ h_{4,4}] \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} + n_4$$

$$y_1 = [h_{1,1}\ h_{1,2}\ h_{1,3}\ h_{1,4}]\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} + n_1 \qquad y_2 = [h_{2,1}\ h_{2,2}\ h_{2,3}\ h_{2,4}]\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} + n_2 \tag{14}$$

Therefore:

$$y = \begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{pmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} & h_{1,4} \\ h_{2,1} & h_{2,2} & h_{2,3} & h_{2,4} \\ h_{3,1} & h_{3,2} & h_{3,3} & h_{3,4} \\ h_{4,1} & h_{4,2} & h_{4,3} & h_{4,4} \end{bmatrix}\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} + n_1 \tag{15}$$

$$H^{+} = (H^{H} H)^{-1}\, H^{H} \tag{16}$$

The reverse of a 4x4 matrix is important for a warning (13). To measure its inverse, new matrix's elements generated through H^{+}, the determinant values are required. Normally, the reverse of a matrix is achieved for co-factors. This technology makes the framework in the H^{+} matrix's higher order more complicated and redundant.

2.3.2 MMSE (Minimum Mean Squared Error) Detector

It's a better algorithm in comparison to the ZF under harsh situations. However, it does not remove ISI as well as the ZF algorithm; this lowers considerably overall power of noise of the user [4].

$$\bar{y}_{MMSE} = (H^{H} H + (\sigma_n / \sigma_s)^2 I)^{-1}\, H^{H} y \tag{17}$$

where σ_s and σ_n represents the received signal power and noise power respectively and identity matrix is represented by I. The estimates of ZF and MMSE are found to be equal when $\sigma_s >> \sigma_n$. Hence, it should be noted that when; the MMSE estimate equates to the ZF estimate. Thus, with the inclusion of a scaling factor, the 2x2 and 4x4 (17) figures can be seen as similar to their ZF equivalents.

2.3.3 Successive Interference Cancellation

This algorithm initially detects, deletes and removes largest individual from the receivable signal. You should do so in two ways. Next, the soft information may be extracted from the obtained signal; it induces little to no error propagation, but for vulnerable users obtains a combined noise effect. Secondly, hard information may be extracted from the received signal which results in little to no noise but potential mistakes. Successive cancellation may be implemented in a circular fashion, at low convergence's cost and therefore higher complexity. MAI is decreased and the problem has evolved almost / far. The most effective and the most accurate cancellation is the cancellation of the best signal [9]. The SIC algorithm will then most likely suffer from error propagation, since the most effective cancellation is possible. The channel estimation at the recipient is also necessary [9]. The ZF or MMSE detector usually is used as pre-filtering for general SIC systems. For the pre-coding, detector utilizing ZF algorithm is investigated as given.

Initial estimates for efficient performance of SIC systems are required. The initial calculations are derived from the ZF detector output. For the 2x2 scenario, the transmitted symbols x1 as well as x2 and for the 4x4 scenario, x2, x3 and x4 are estimated depending on number of antennas.This is then taken by the SIC detector and deducted from actual data stream. The total iterations number depends once more on used antennas numbers. Only one estimate is necessary, in a 2x2 scenario, whereas three estimates are needed in the 4x4 scenario.The estimates of a 2x2 and a 4x4 MIMO system may, as illustrated below, be expressed by using (8) shown for a ZF detector.

$$\begin{bmatrix} \widetilde{x}_1 \\ \widetilde{x}_2 \end{bmatrix} = H^{+} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \tag{18}$$

$$\begin{bmatrix} \widetilde{x}_1 \\ \widetilde{x}_2 \\ \widetilde{x}_3 \\ \widetilde{x}_4 \end{bmatrix} = H^{+} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} \tag{19}$$

The incident signal received at the first antenna, y1 has been seen underneath when a 2x2 MIMO system is adopted to make it easy.

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = [h_{1,1}\ h_{1,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \tag{20}$$

Therefore, at the second receiver, the received signal matches with y_2 below.

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1}\ h_{2,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \tag{21}$$

Utilizing (1) where

$$y_m = \sum_{n=1}^{N} h_{mn}x_n + n_n \qquad \mathrm{m} = 1,2,\ldots,\mathrm{M} \tag{22}$$

$$y = Hx + n$$

The ZF approach is used for simple purposes because the ZF and MMSE counterparts can be considered to be substantially similar via a weighing factor. Input signal estimates are decoded by using a ZF algorithm to meet a limit below in which H^{+} is a matrix with the parent matrix 'size, H which shows the ratio shown in (23).

$$H^{H}H = I \tag{23}$$

Identity matrix is represented by *I* and utilizing an identity matrix's convenient properties [8], the H^{+} matrix, is represented as:

$$H^{+} = (H^{H}H)^{-1}\, H^{H} \tag{24}$$

The received estimates can be represented as seen in (25), by means of the relation in (22) for solving the estimates received.

$$\begin{bmatrix} \bar{x}_1 \\ \bar{x}_2 \end{bmatrix} = H^{+} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \tag{25}$$

$$\begin{bmatrix}\bar{x}_1\\ \bar{x}_2\end{bmatrix} = (H^H H)^{-1} H^H \begin{bmatrix} y_1\\ y_2\end{bmatrix} \tag{26}$$

It has been supposed that in (26) estimates have been provided that are to be subtracted as first estimates, furthermore, received signal consists of $\tilde{x}_1$, that is remaining estimate only as provided in (27).

$$\begin{bmatrix} r_1\\ r_2\end{bmatrix} = \begin{bmatrix} h_{1,1}\\ h_{2,1}\end{bmatrix} x_1 + \begin{bmatrix} n_1\\ n_2\end{bmatrix} \tag{27}$$

It can be seen from (27); because, after one iteration, at the receiver the incident signal comprises of a particular symbol, but further iterations are necessary in cases with a larger number of transmission antennas, and the composition of that signal is a mixture of other transmitted signal components. The first prototype for a 4x4 MIMO device can be seen from the descriptor of the obtained signal.

$$\begin{bmatrix} r_1\\ r_2\\ r_3\\ r_4\end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} & h_{1,4}\\ 0 & 0 & 0 & 0\\ h_{3,1} & h_{3,2} & h_{3,3} & h_{3,4}\\ h_{4,1} & h_{4,2} & h_{4,3} & h_{4,4}\end{bmatrix} \begin{bmatrix} x_1\\ 0\\ x_3\\ x_4\end{bmatrix} + \begin{bmatrix} n_1\\ 0\\ n_3\\ n_4\end{bmatrix} \tag{28}$$

The new values for the H matrix are modified according to every iteration, that is the h values for the preceding value are adjusted to zero as well as the iteration is repeated for the r new value before all the symbols are decoded.

2.3.4 OSIC (Ordered Successive Interference Cancellation) Algorithm

The detection algorithm used in this project is a non-linear equalization method. Co-Antenna Interference, CAI, is the key limitation in MIMO systems. The OSIC algorithm is readily used to prevent this disability. The incoming sub streams i.e., layers are identified by this algorithm recursively. It can identify the strongest layer first, that is to say, the highest SNS sub line, as well as after that delete it from the actual signal obtained so that the CAI can be correctly extracted. The process continues the procedure for layers afterwards; the signal intensity is used for detecting and extracting from the initial signal all of the sub-streams / layers available [10].

The successive interference cancellation approach requires ordering as the mistakes connected with previously observed layers will be continuously related to the detection system. Therefore, layers with lower probability of error must first be observed before other layers are observed. In the following three key steps the ordering process and the OSIC algorithm can be shown.

2.3.4.1 Interference Cancellation

The interruption of the transmitter will occur when the mark is sensed. This interruption is extracted from the initial signal obtained as seen in the mathematical expression.

$$y' = y - h_1 \bar{y}_1 - \ldots - h_{i-1} \bar{y}_{i-1} \tag{29}$$

where within the matrix H, respective i_{th} column is represented by h_i, y the received signal's estimated hard decisions are represented by y_i.

2.3.4.2 Interference Nulling

This method is very critical and typically takes a linear equalizer. This is a very important technique. This is performed using MMSE or ZF in existing systems [10]. The MMSE algorithm was utilized by this project.

2.3.4.3 Optimal Ordering

The design of the detection pattern of SIC systems is a significant source of error propagation. This will impair the overall BER output if sub-strains with high probability of error are observed and eliminated in the early stages of the detection from the reception system. This will allow the acquired error to propagate across the entire chain of identification. This error propagation is avoided by optimum ordering by allowing the line to be identified earlier in the obtained signal vector with the maximum SNR post detection. Therefore, immediately after the interruption zero's occurrence inside the OSIC decoder there is an optimum ordering mechanism.

3. Simulations and Results

In the case that a mxm MIMO channel is available, the data will be sent in a single antenna-scenario chain, $x = [x_1, x_2, x_3, x_4 ..., x_n]$, normally and data will require data slots for transmitting the data-stream. Here the "*mxm* MIMO detector" in which "m" antennas are available, data for regular transmission can be transmitted at "m" time the actual data rate. The "m" symbols can be included now with any system. This occurs. In a 2 x 2 scenario, for example, x1, x2 are sent to the first timepiece with x3 from both transmit antennas, x4 in the second timepiece and the like. The data rate is quadrupled in the case of *4 x 4* MIMO when four symbols are sent in any time frame. The other key theories that are used are:

- Flat Rayleigh fading is experienced by the channel
- At the receiver, from (2), the channel matrix, H is received

3.1 MIMO System's Capacity

The abovementioned potential in (7) were achieved by utilizing value decomposition theory [41] as well as tested for various transmitter and recipient combinations. A pattern in terms of the observed ability increase in a growing antennas number, as represented in Fig. 3-7, is automatically recognized.

3.2 Implementation Utilizing Various Receiver Configuration

OSIC, MMSE and ZF varieties were tested. ZF-OSIC, MMSE-OSIC, MMSE and ZF are tested for receiver variants. A comparison message of n to 1x105 bits sent by a fading channel Flat Rayleigh. The modulated signals transmitted were divided in right streams that are antenna suitable. For example, the signal should be broken up in 4 different data streams with a 4x4 system, as well as a 2x2 system would need 2 stream, and so on. The BER output of two separate receptor combinations as seen in Fig. 3-8 as well as 3-9 respectively.

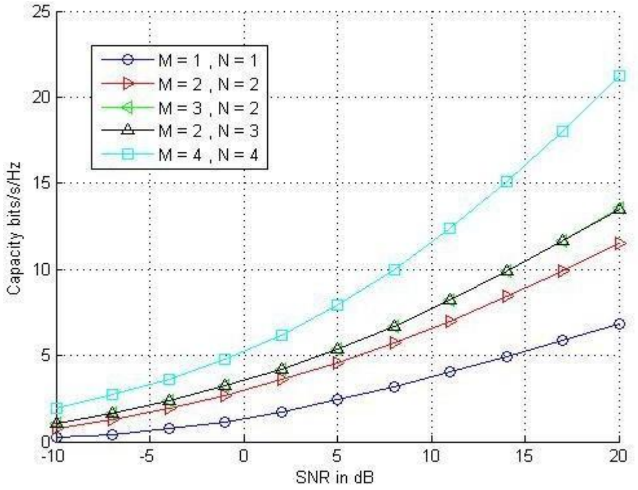

Figure7: Various MIMO Configurations' Capacities

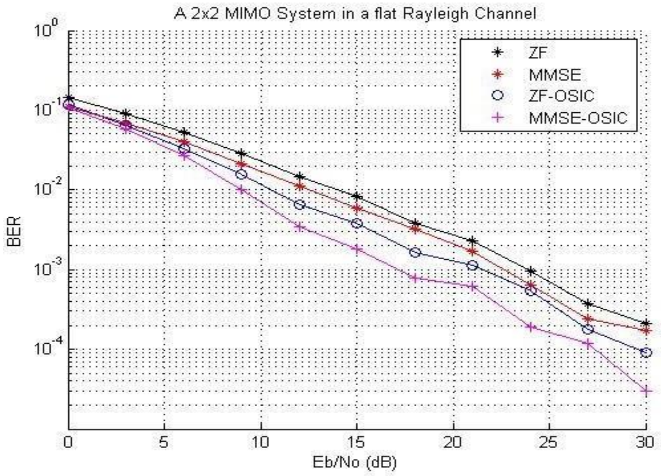

Figure8: 2x2 MIMO with different Receive Architectures

4. Conclusion and Summary

As overall antennas number seen in Figure3 thus grows the power of a standard MIMO device. The capabilities of an N-familial MIMO systems are similar as those of M-familiar MIMO systems.

Adding SIC to the MMSE as well as ZF MIMO receiver gives some changes to enhancements of BER value, but such minor change is important while ordering is performed with SIC according to fig. 3–8 as well as 3–9. It is noticed that the output BER images for MMSE-OSIC to ZF-OSIC are now comparable in Fig. 3-10, while 16PSK is being used, although BER values are still higher in MMSE-OSIC. Figure10 indicates the achievable BER values by including an optimum ML decoder, which needs even more device complexities, is also used in an ML decoder.

A 2x2MIMO system, based on the simple ZF detector, was studied as represented Fig. 3-11. As total symbols transmitted per second increases, the total errors also increases as well as thus, there exists requirement for higher SNR values. Figure11 also shows the need for higher SNRs to be used for greater order modulation.

The particular paper provides a typical MIMO system's brief introduction. Compared to above-developed user systems, modern modern systems adopt a multi-user scenario. The present requirement for higher data rates resulted in the various techniques use like OFDM by the industry and the additional use of MIMO capabilities in WIFIs and CDMA. The next paper examines the integration of multi-user MIMO with receiving architectures.

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