Original Article

Performance Evaluation Of Different Mimo Systems

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Abstract

With each passing year, there is a rapid increase in mobile data traffic and also there occurs a demand for bringing a higher data rate to a growing number of users. The next generation networks need to depend on denser infrastructure deployment, reduced inter- and intra-cell interference, [2] simple signal processing, and reduced transmitted power, as well as improved energy and spectral efficiency, to provide seamless connectivity. The mathematical modeling of MIMO systems is discussed, with emphasis on the technology's key features. The latest developments in the MIMO area, such as Multi-user MIMO (MU-MIMO) [1], Massive MIMO, and MIMO OFDM techniques, are then discussed in detail, with an emphasis on their importance in cellular communication systems. Massive MIMO has been regarded as the best approaches to increase spectral and energy efficiency in broadband wireless communication systems. The massive MIMO's channel model must be explored as the first step in evaluating the performance of any communication system.

Keywords - MIMO, MU-MIMO, Massive MIMO, MIMO-OFDM.

I. INTRODUCTION

[1] A smart antenna array group called MIMO which stands for "Multiple Input Multiple Output". This method uses so many transmit and receive antennas in order to enhance transmission data rate and improve system reliability by deploying spatial multiplexing. MIMO systems accomplish these benefits by utilizing scattering effects from several routes without the need for increased capacity. A MIMO system requires no additional bandwidth because each antenna operates on the same frequency. Numerous copies of the same signal is being supplied to the receiver with the help of MIMO system, even if a channel is damaged by fading effect, which will affect the error rate [1].

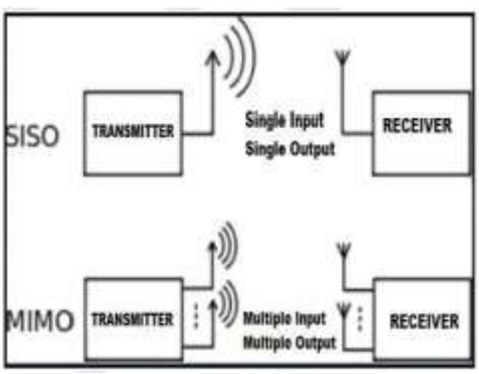

Figure.1. Basic Difference Between SISO and MIMO System

The basic working principle behind MIMO is that the premise of providing many copies of the same signal to the receiver end. If the signal channel can be engineered to affect these in separate paths, the likelihood of them all being affected at the same time is much decreased and it helps to normalize a connection and increase the performance by lowering the system error rate. [1] The capacity of a given channel is greatly improved by MIMO technology due to the usage of multiple antennas at both transmitter and receiver side. With each pair of antennas added to the system, the throughput of the channel can be maximized in proportionate to the maximizing number of receiving and transmitting antennas [1]. The most recent MIMO technique named as geometric mean decomposition (GMD) [3] which combines the diversity and data rate maximization aspects of MIMO in an efficient manner. The advantages of orthogonal frequency division multiplexing together with MIMO system provides the best solution for next generation wireless communication systems.

II. MIMO SYSTEM CATEGORIZATION

There are three categories in MIMO systems: Precoding, Spatial Multiplexing (SM), and Diversity Coding [1].

A. Precoding

It uses transmit diversity which is a pre-processing approach to allow the receiver to decode the received signal without knowing the channel beforehand. For example, suppose we are delivering data and it passes through the channel h, where white Gaussian noise n is being added, at the receiver front-end, the received signal will be **r = hs+n** [1].

The receiver must have prior knowledge of h in order to extract the information (the influence of n can be nullified by maximizing the Signal to Noise Ratio). This may add to the receiver's complexity, but it's preferable to make it less and modest value. We forecast the channel at the transmission end to achieve this purpose (base station). Let's refer to the predicted channel as h_{est}. Instead of sending s, we are now sending **s/** $h_{est.}$ The received signal will be

$$\mathbf{r} = \mathbf{s}\frac{h}{h_{est}} + \mathbf{n}$$

If the prediction is accurate, then in that case; $h=h_{est}$, we receive **r = s+n**

B. Spatial multiplexing

A stream is a data transmission that is independent and encoded independently. [1] A higher data rate signal is splitted into so many lower-rate streams in spatial multiplexing, with every stream transmitted from a various transmit antenna in the similar frequency channel. It is the most effective method for boosting the capacity of the channel at greater Signal to Noise Ratio. The technology, also called as [11] space-division multiple access or multi-user MIMO, can be utilized for simultaneous transmission to several receivers and the channel state information (CSI) is required at the transmitter in this case.

C. Diversity Coding

No information about the channel is available at the transmitter side, this strategy is utilized. Only one stream is delivered in diversity coding (as opposed to several streams in spatial multiplexing), and space-time coding techniques are used to code the signal. With full or near orthogonal coding technique, from each side of the transmitting antennas, the signal is radiated. [1]

III. MIMO MATHEMATICAL MODEL

[5] The three primary components of MIMO systems are the transmitter (T_X), the channel (H), and the receiver (R_X). The Multiple-Inputs are found at the T_X's output, while the Multiple-Outputs are found at the R_X's input.

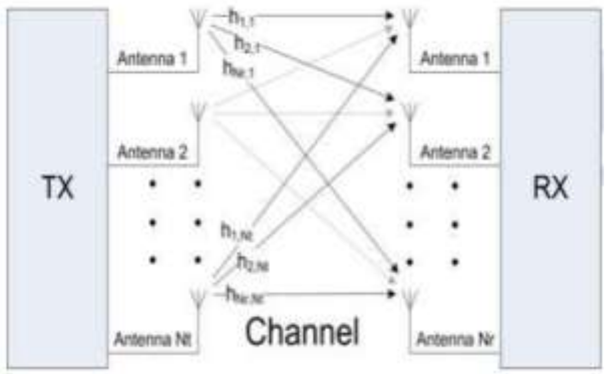

Figure.2. System Model for MIMO [1]

Define

{R: Data rate (bits/symbol)

R_s: Symbol rate (Symbols/second)

W: Allotted Bandwidth (Hz)

SNR: Signal to Noise Ratio

P_e: Probability of error

N_R: Number of receivers

N_T: Number of transmitters} [1]

The spectral efficiency of the system is given by;

$$\eta = \frac{RR_s}{W}$$

For required signal reconstruction, the condition $R_s \leq W$ should be satisfied. As a result, $\eta \leq R$. We can get an arbitrarily low P_e by having the data transmitted at a data rate $R \leq C$, where R is the data rate and C is the channel capacity.

Model of a MIMO system is as follows:

$$\vec{y} = H\vec{s} + \vec{n}$$

Where the transmitted vector is S, the received vector is y; the noise vector is n and each and every element being modeled as independent identically distributed (i.i.d) white Gaussian noise with variance σ=(2xSNR) and H is the channel matrix [1].

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N_T} \\ h_{21} & h_{22} & \cdots & h_{2N_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_R1} & h_{N_R2} & \cdots & h_{N_RN_T} \end{bmatrix}$$

where h_{ij} represents the attenuation (along with its phase) transfer function (i.e. fading gain) between transmitter i and receiver j and it is a complex Gaussian random variable. The normalized white Gaussian noise (AWGN) is given by n.

At high SNR, the channel capacity of MIMO has a multiplexing gain of min(N_T, N_R). Similarly by keeping SNR constant and also by increasing N_T and N_R [12], capacity varies as,

$C_{Equal\ Power}$ = min(N_T, N_R) x constant

Which means that the capacity of channel increases proportionally with the increasing number of antennas. The slopes of the lines have equal value of min(N_T, N_R) have similar slopes at high SNR [11].

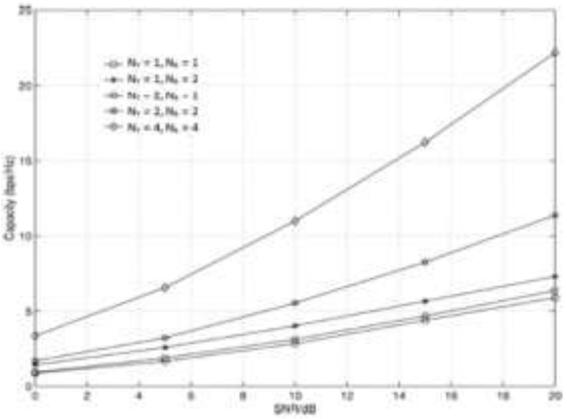

Figure.3. Capacity vs SNR for Different Antenna Sizes

IV. MULTI-USER MIMO, MASSIVE MIMO & MIMO-OFDM

Multi-User MIMO (MU-MIMO) is the concept where at the simultaneous time MIMO is utilized to share with several terminals. In wireless communication systems, so many antennas are used in order to send and receive multiple data from multiple terminals at the same time [1].

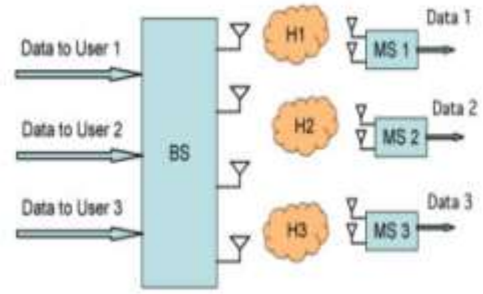

Figure.4.MU-MIMO System Model

In its traditional form, this technology for mobile communications is currently being included into newer wireless broadband standards. The more antennas a base station (or terminal) has, the better its performance in all areas: greater data rate, improved dependability, [1] enhanced energy efficiency, and less ISI, when using the concept of time-division duplexing (TDD). The benefits of this technology arise at the cost of extra hardware – transmitting and receiving antennas and processing - as well as the cost of obtaining channel state information (CSI), which necessitates the available bandwidth usage.

A new technique called Massive MIMO which has the potential to scale up MIMO in orders of magnitude over existing techniques [1]. This system refers to MIMO systems which employ group of antennas with hundreds of antennas to serve tens of terminals in the same time-frequency resource simultaneously. [11] The fact that the number of terminals is substantially lower than the number of base station antennas is a major aspect of massive MIMO technology. As previously stated, the number of antennas increases the capacity and efficiency of MIMO systems. Massive MIMO's core assumption is to gain all of the benefits of conventional MIMO on a much larger scale. Simple beam forming algorithms such as maximum ratio transmission (MRT) [11] or zero forcing (ZF) can be used to fully leverage the benefits of a massive MIMO system in a rich scattering environment [6]. To get the benefits of large MIMO, precise CSI must be accessible at all times.

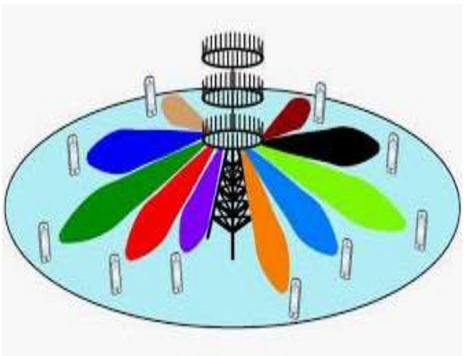

Figure.5. Basic Structure of Massive MIMO System [13]

The combination of MIMO and OFDM algorithms is the crucial air interface for 4G and 5G broadband wireless communications. It combines MIMO's improved capacity, data throughput, and spectrum efficiency, as well as OFDM's bandwidth-sharing ability and simplicity, to enable more reliable communications at higher rates than 3G. [1] MIMO technology can be utilized with other prominent air interfaces like as time division multiple access (TDMA) and code division multiple access (CDMA), although the combination of MIMO with OFDM is most feasible at increased data rates, according to research conducted in the mid-1990s.

MIMO-OFDM concept is used to build Advanced wireless local area network (wireless LAN) and mobile broadband network standards. Raleigh demonstrated [1] that many data streams could be communicated simultaneously on the identical frequency by using the concept that signals carried through space bounce off things and follow various pathways to the recipient. [11] Separate data streams could be delivered over various pathways by employing many antennas and precoding the data [1].

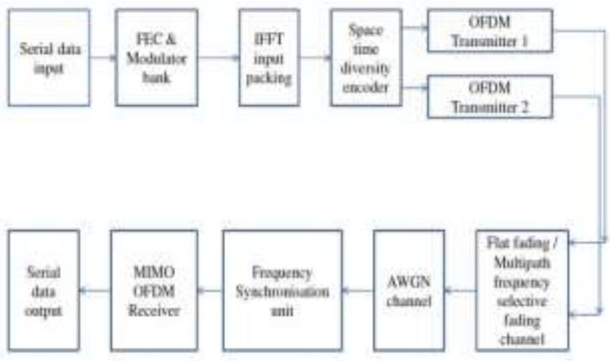

Figure.6. MIMO-OFDM System Model

V. MASSIVE MIMO CHANNEL MODEL

To assess the wireless communication systems performance, two common types of channel models are used: correlation-based stochastic models (CBSMs) and geometry-based stochastic models (GBSMs) [8]. The former has a lesser level of complexity and is mostly used to analyze the performance of MIMO systems theoretically. However, the accuracy of a true MIMO system is restricted, and modeling wireless channels with non-stationary phenomena and spherical wave effects is difficult. Even with the higher processing complexity, GBSM's can correctly reflect realistic channel parameters and are more suitable for huge MIMO channels.

[10] Table. 3: Massive MIMO Channel models [9]

Modeling Method	Category	Property
CBSM	Independent identically distributed Rayleigh channel model	Elements of fast fading are Independent identically distributed complex Gaussian variables
	Correlation channel model	It contains correlation between transmit and receive antennas
	Mutual coupling channel model	This type of model consider various impedances like the antenna impedance, load impedance, and mutual impedance
GBSM	2D channel model	This model propagates beam on 2D plane, such as linear array
	3D channel model	This type of model propagates beam on 3D plane, such as spherical, rectangular, and cylindrical array

VI. CHANNEL ESTIMATION

In wireless communication, channel estimation is essential. The channel fluctuates with time in real time, and is affected by a variety of elements such as changes in the environment, surrounding buildings, barriers scattering the signal. [5]

$y=Hx+N$ represents the system model. The Rayleigh channel is represented by H, which is a matrix containing all of the channel characteristics that correspond to their channel path. AWGN channel is denoted by N and it is a matrix once again. The variance of noise is controlled by the SNR in this case. The information conveyed is contained in the signal component x. The received signal y is used to estimate the channel for the Training Based Channel Model (TBCM) and Blind Channel Estimation (BCE) techniques.

A. Training Based Channel Estimation

[24] The TBCE approach employs trained/pilot sequences that are both recognized by both the transmitting and receiving ends. In previous to the delivery of the data containing the necessary information, the trained sequence is sent. These training sequences are used by the receiver to evaluate the channel and decrease the channel effects. At receiver side, the error produced by noise in the channel is decreased using the Minimum Mean Square Estimator.

Table.4. Bit Error Rate Comparison for QPSK and 16-QAM Modulation Schemes for Varying SNR in Training-Based Channel Estimation [5].

SNR (db)	Conventional MIMO (BER)		Massive MIMO (BER)	
	QPSK	16-QAM	QPSK	16-QAM
0	1.1256	1.56	1.23	1.8550
5	0.8488	1.2969	0.0725	0.1231
10	0.5119	0.8788	0.0013	0.0019
15	0.2463	0.4625	0	0
20	0.1038	0.2037	0	0
25	0.0362	0.0456	0	0

B. Blind Channel Estimation

With the use of BCE, the need for training sequences can be eliminated, thereby relying on the natural constraints of the channel for the channel estimation. The channel model is assumed to be Rayleigh fading in order to account for the realistic channel. The estimation of symbols travelled through the noisy channel is done blindly without having the pre-estimated parameters of the channel which eliminates the use of pilot symbols and in turn makes it bandwidth efficient [5].

Table.5. Bit Error Rate Comparison for QPSK and 16-QAM Modulation Schemes for Varying SNR in Blind Channel Estimation [5].

SNR (db)	Conventional MIMO (BER)		Massive MIMO (BER)	
	QPSK	16-QAM	QPSK	16-QAM
0	0.1392	0.5566	0.0028	0.0111
5	0.0419	0.1676	0.0008	0.0034
10	0.0018	0.0070	0	0.0001
15	0	0.0001	0	0
20	0	0	0	0
25	0	0	0	0

VII. PERFORMANCE COMPARISON

[1] The given table compares MIMO systems' efficiency of the spectra and data rate to that of other modern wireless systems. [11]

Table.1. Performance Comparison of Various Technology

Technology	Max. Spectral Efficiency (bits/s/Hz)	Max. Bitrate (Mbits/s)
3G	2.5	3.075
3.5G	4.22	21.1
4G SISO	4	72
4G MIMO (4X4)	16.32	81.6
4G MIMO (8X8)	30	75

The below figure compares BER in various system technologies with the equal number of antennas. [1]

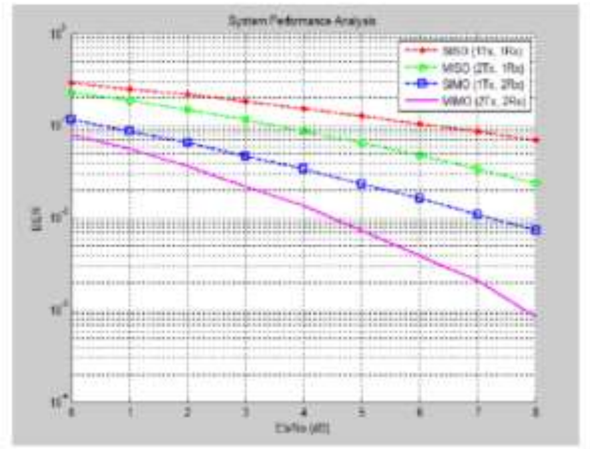

Figure.7. BER Performance Comparison of SISO, MISO, SIMO and MIMO Systems [1]

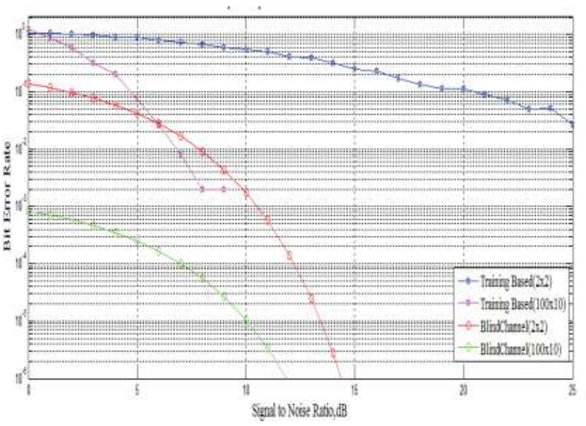

Figure.8. Comparison Plot for Conventional MIMO and massive MIMO [5]

VIII. SUMMARY

Since many data symbols are transmitted simultaneously utilizing multiple antennas in a MIMO system, the data rate is increased. By having several antennas to broadcast the same signal, MIMO communications channels solve the fading and multipath challenges. To gather knowledge about the communications channel, these systems use a mix of many antennas and numerous signal pathways. A receiver can get back the separate streams from each of the transmitter's antennas when using MIMO. At all data rates, MIMO configurations exceed the capacity provided by the Shannon-Hartley limit, making these systems appealing for better data throughput. While these types of systems give evident benefits to consumers at the application level, designing and testing MIMO devices is not without its difficulties. [1] MIMO-OFDM, MU-MIMO, and Massive MIMO communications systems are projected to see continuous development due to system benefits such as increased data rate, capacity, and multipath robustness. If upgraded MIMO techniques deliver on their promise, future wireless networks will be quicker, able to accommodate more users, and have improved reliability and energy efficiency.

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REFERENCES

[1] Advances in MIMO: System Model and Potentials Snehil Verma,AdityaVikram,Vikas Kumar
[2] www.mdpi.com
[3] Y. Jiang, J. Li, and W. W. Hager, Joint transceiver design for MIMO communications using geometric mean decomposition, IEEE Transactions on Signal Processing, Vol. 53, No. 10, pp. 37913803, October 2005.
[4] en.wikipedia.org
[5] M.Pappa, C.Ramesh "Performance Comparison of Massive MIMO and Conventional MIMO Using Channel Parameters" IEEE International Conference on WiSPNET 2017.
[6] Tebe Parfait, Yujun Kuang, Kponyo Jerry, "Performance Analysis and Comparison of ZF and MRT Based Downlink Massive MIMO Systems".
[7] Raleigh, G.G.; Cioffi, J.M. (1996). Spatio-temporal coding for wireless communications. IEEE Global Telecommunications Conference, 1996. London November 1822, 1996. pp. 18091814 vol. 3.
[8] Soujanya Thallapalli, Rajoo Pandey. "Performance Evaluation of Channel Estimation in Multicell Multiuser

Massive MIMO Systems", 2019 International Conference on Vision Towards Emerging Trends in Communication and Networking (ViTECoN), 2019.
[9] Kan Zheng, Suling Ou and Xuefeng Yin, " Massive MIMO Channel Models – A Survey" International Journal of Antennas and Propagation,Volume 2014, Article ID 848071,10 pages http://dx.doi.org/10.1155/2014/848071
[10] www.hindawi.com
[11] https://en.wikipedia.org.
[12] B. Hochwald and S. Vishwanath, Space-time multiple access: Linear growth in sum rate, in Proceedings of 40th Annual Allerton Conference on Commun., Control and Computing,Oct.2002.
[13] R.Ramalakshmi, S.Tamil Selvi, "Energy Efficient Techniques in 5G Wireless Communication – A Survey" International Journal of Scientific Research and Review, Volume 9, Issue 9, pp:22-30 September 2020, ISSN:2279- 543X.