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Development of MCM-MIMO processing for Urban Cellular Link

16EC73P : BE Minor Project Phase _ Presentation

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Outline

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- Objectives of the project
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Introduction

- Multipath propagation in single channel systems leads to signal interference and causes degradation of information.
- In urban cellular networks, this disadvantage can be used to our benefit by using the concept of spatial diversity and spatial multiplexing
- Diversity is a concept in which the receiver receives multiple versions of the same signal so that even if one signal is corrupted, information is not lost.
- Multiplexing involves using these different spatial channels to enhance capacity

Introduction

- In order to carry out MIMO , modulation has to be done first in Multi Carrier mode
- Multicarrier modulation, MCM is a technique for transmitting data by sending the data over multiple carriers which are normally close spaced.
- Multicarrier modulation has several advantages including resilience to interference and resilience to narrow band fading.
- As a result, multicarrier modulation techniques are widely used for data transmission as it is able to provide an effective signal waveform which is spectrally efficient and resilient to the real world environment.

Motivation

- With increase in number of mobile users, the data requirements is shooting up exponentially
- At present, MIMO is being used in spatial diversity mode which limits the capacity
- Hence it is desirable to operate MIMO in multiplexing mode as well in order to maintain a given QoS

Literature Survey

Sl No	Paper Title Journal Name, Year	Major findings / observations
1	Data Transmission by Frequency - Division Multiplexing Using Discrete Fourier Transform - ***IEEE Transactions on Communications Technology***, **1971**	• Sampling MCM signals in transmitter • These samples signal is imply the IDFT of information symbol. • One simple IDFT block instead of N modulators
2	Generation of Pseudorandom Binary Sequences by Means of Linear Feedback Shift Resistors (LFSRs) With Dynamic Feedback – ***Elesevier Journals on Mathematical and Computer Modelling***, **2011**	• 2 LFSRs used of PRBS generation • M - length LFSR acts as address to N - length LFSR • Higher level of randomness when compared with 1 LFSR generator

Literature Survey

Sl No	Paper Title Journal Name, Year	Major findings / observations
3	Closed - Form CLRBs for CFOs and Phase Estimation from Turbo Coded Square QAM Modulated Transmissions – ***IEEE Transactions on Communications Technology***, **2015**	• Recursive construction of higher order QAM constellation • Start from 4QAM or 8QAM for even or odd number of bits respectively • Saves memory
4	Asymmetric digital subscriber line transceivers 2 (ADSL2) – ***Telecommunication Standardization of ITU***, **2009**	• CREVERB1 for generation of PRBS • Computationally less complex way to generate PRBS • Recursive construction of QAM constellation as per ITU standards

Literature Survey

Sl No	Paper Title Journal Name, Year	Major findings / observations
5	Adaptive Loading in MIMO/OFDM Systems – ***Semantic Scholar***, **2001**	• Adaptive Loading • Energy Minimization problem • Based on Shannon Capacity Law
6	A Practical Discrete Multitone Transceiver Loading Algorithm for Data Transmission over Spectrally Shaped Channels – ***IEEE Transactions on Communications***, **1995**	• DMT Loading Algorithm • Iterative computation of gamma • Compute for required data rate and given SNR

Literature Survey

Sl No	Paper Title Journal Name, Year	Major findings / observations
7	A simple transmit diversity scheme for wireless communications – ***IEEE Journal on Selected Areas in Communications***, **1998**	• Orthogonal Space Time Block Coding (OSTBC) for MISO system • The channel becomes orthogonal due to coding scheme • Transmitter need not know channel coefficients
8	Orthogonal frequency division multiplexing: a multi-carrier modulation scheme – ***IEEE Transactions on Consumer Electronics***, **1995**	• Implementation of Orthogonal Space Time Multiplexing • Assigning different order of modulations or power levels to different sub-carriers

Literature Survey

Sl No	Paper Title Journal Name, Year	Major findings / observations
9	The Singular Value Decomposition: Its Computation and Some Applications – ***IEEE Journal on Automatic Control***, **1980**	• Computation of SVD matrices • Numerical determination of rank • Applications of SVD
10	Wireless communication systems with-spatial diversity: a volumetric model – ***IEEE Transactions on Wireless Communications***, **2006**	• Physical-modeling approach to wireless systems with multiple antennas • Computation of degrees of freedom • Simple modelling of multi path channels

Problem Statement

- The problem statement we try to address is the improvement of capacity and data rates in wireless communication systems.
- Using SISO systems, theoretically one can achieve high rates. However, there is a current discomfort with the design of these systems as there is a need to design complex equalizers, allocate large power budgets or have cost prohibitive modems all of which make SISO systems unviable for communication.

Objectives of the Project

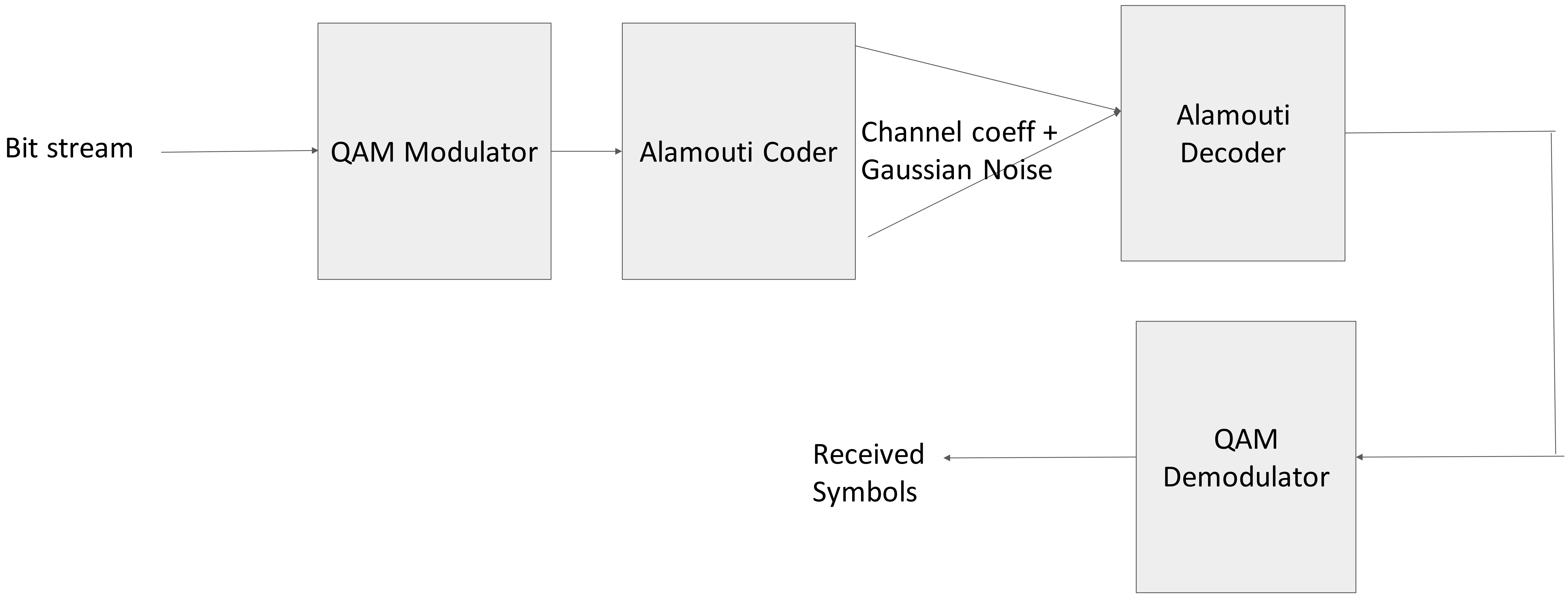
- The objectives of the project is to build a 2x2 MIMO systems to examine ways to improve QoS for 2 antenna systems in low SNR regimes and capacity enhancement in high SNR regimes.

Design Methodology

The basic methodology of this project is

1. Develop an effective channel model for 2 x 2 MIMO links
2. Develop an efficient transmitter and receiver supporting MCM and MIMO processing.

Design Methodology



Details of Software / Hardware

- The simulation of this project was done with the help of Matlab
- The ultimate goal of this project was to design a 2x2 MIMO system and in this regard, first a SISO system was designed to lay the foundation for multi carrier communication systems.
- Further, a 1 x 2 SIMO system was designed to operate in diversity mode. OSTBC was implemented for a 2 x 1 MISO system. Finally, a 2x2 MIMO system was designed to work in both diversity and multiplexing modes to improve the data rates and capacities.
- The design of this system employed unique precoding schemes and computational methods like Alamouti coding, Inverse Channel Estimation precoding and SVD.
- We also demonstrated the use of Rayleigh fading and Friis' path loss formula for real world simulation purposes.

Details of Alamouti Coding Scheme

a

- Consider two transmitting antennas T_1 and T_2 and a receiving antenna R.
- Let h_1 be the channel coefficient for antenna path 1 and h_2 for antenna path
- Let x_1 and x_2 be the two message vectors transmitted by T_1 and T_2 at a given time instance. And $-x_2^*$ and x_1^* be the message vectors transmitted in the next time instance.
- Since the channel behaves as an LTI system, it performs convolution of channel coefficients and data bits. Also, the channel adds AWGN noise vectors w_1 and w_2 respectively at the two time instances.
- This situation can be mathematically represented as follows

Details of Alamouti Coding Scheme

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- $y_1 = [h_1, h_2] \times \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + w_1$
- $y_2 = [h_1, h_2] \times \begin{bmatrix} -x_{2^*} \\ x_1 \end{bmatrix} + w_2$
- $y = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = C_1 x_1 + C_2 x_2 + w$
- Where $C_1 = \begin{bmatrix} h_1 \\ h_2^* \end{bmatrix}$
- And $C_2 = \begin{bmatrix} h_2 \\ -h_1^* \end{bmatrix}$
- Here C1 and C2 are orthogonal in nature hence this coding is also called Orthogonal Space Time Block Coding (OSTBC)
- At the receiver the matrix y is obtained and x_1 and x_2 can be recovered as follows

Details of Alamouti Coding Scheme

- $\frac{C_1^H}{\|C_1\|} y = \|C_1\| x_1 + \bar{w}_1$
- $\frac{C_2^H}{\|C_2\|} y = \|C_2\| x_2 + \bar{w}_2$

a

Here H is the Hermititan operation. It is noticed that both x1 and x2 are both scaled by a factor and mixed with AWGN noise. With a suitable decision criteria both x1 and x2 can be decoded correctly in 2 time slots. However, in higher order schemes Alamouti coding loses its efficiency and is not feasible.

Inverse Channel Estimation

- The received symbol vector y is related to the transmitted vector x and channel coefficient matrix h as follows
- $y = h * x + n$
- Where n is the AWGN noise vector
- From this we can extract the sent symbols by multiplying y with h^{-1} where
- $Y * h^{-1} = x + w_1$.
- Further processing is required to remove w_1 but the issue is that w is no longer AWGN but becomes coloured noise. Therefore, to overcome this hindrance we precode the transmitted vector x by multiplying with h^{-1}. Then,
- $Y = x * (h^{-1} * h) + n * h$
- $Y = x + w_2$
- Where w_2 is now AWGN noise and processing becomes simpler.

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Singular Value Decomposition

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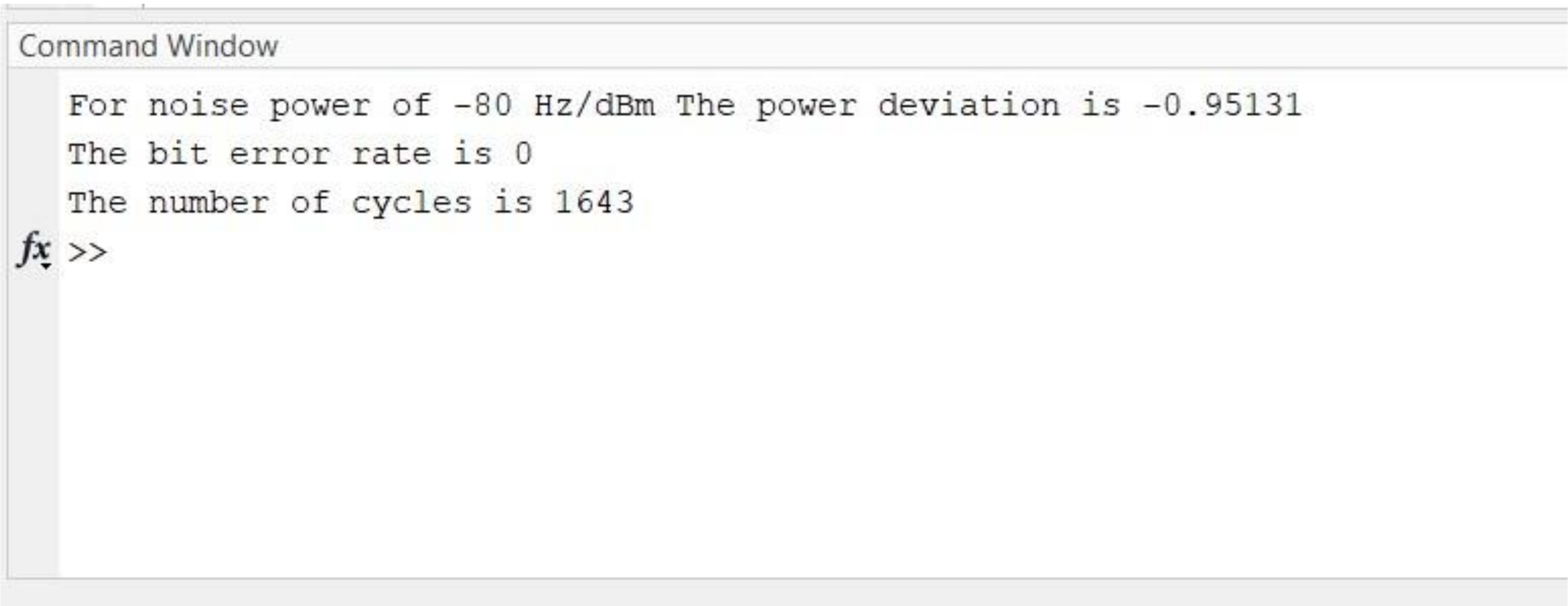
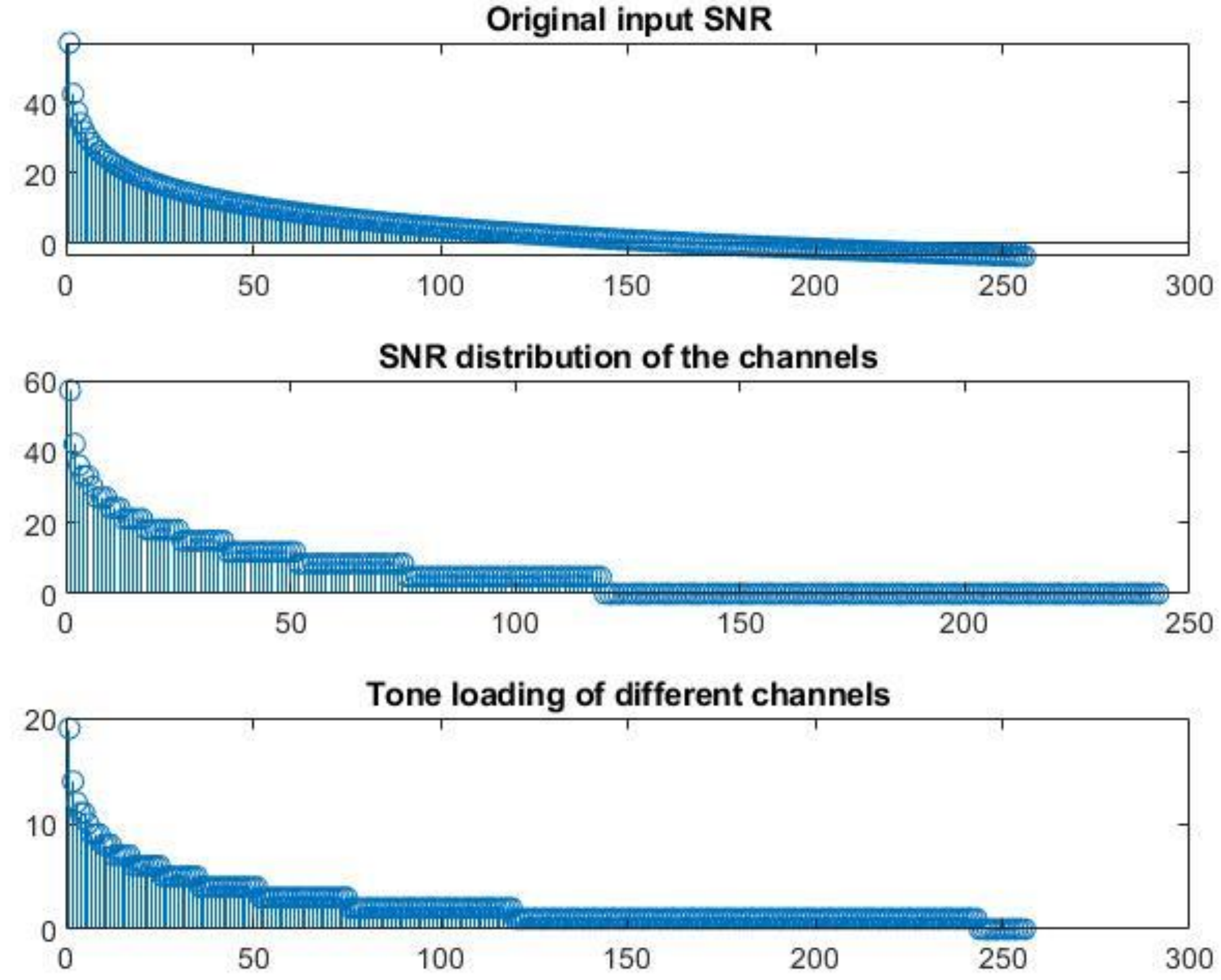
- In massive MIMO systems where the number of antenna paths are plenty and the order of the channel coefficient matrix is large, inversion of matrices becomes a computationally intensive task.
- Since it is required to have high speed modems which do not take more than a few microseconds to make the necessary computations, one must look to faster ways of inverting the channel coefficient matrix.
- In this effort we use SVD technique where the channel coefficient matrix h is decomposed into 3 orthogonal matrices U, ∑ and V
- At the transmitter one multiplies the transmitted vector with V and similarly at the receiver the received vector is multiplied by U to achieve the same effect as channel inversion.
- Singular value decomposition is faster than regular inversion for large matrices and hence proves faster in massive MIMO systems.

Results

SISO System Results



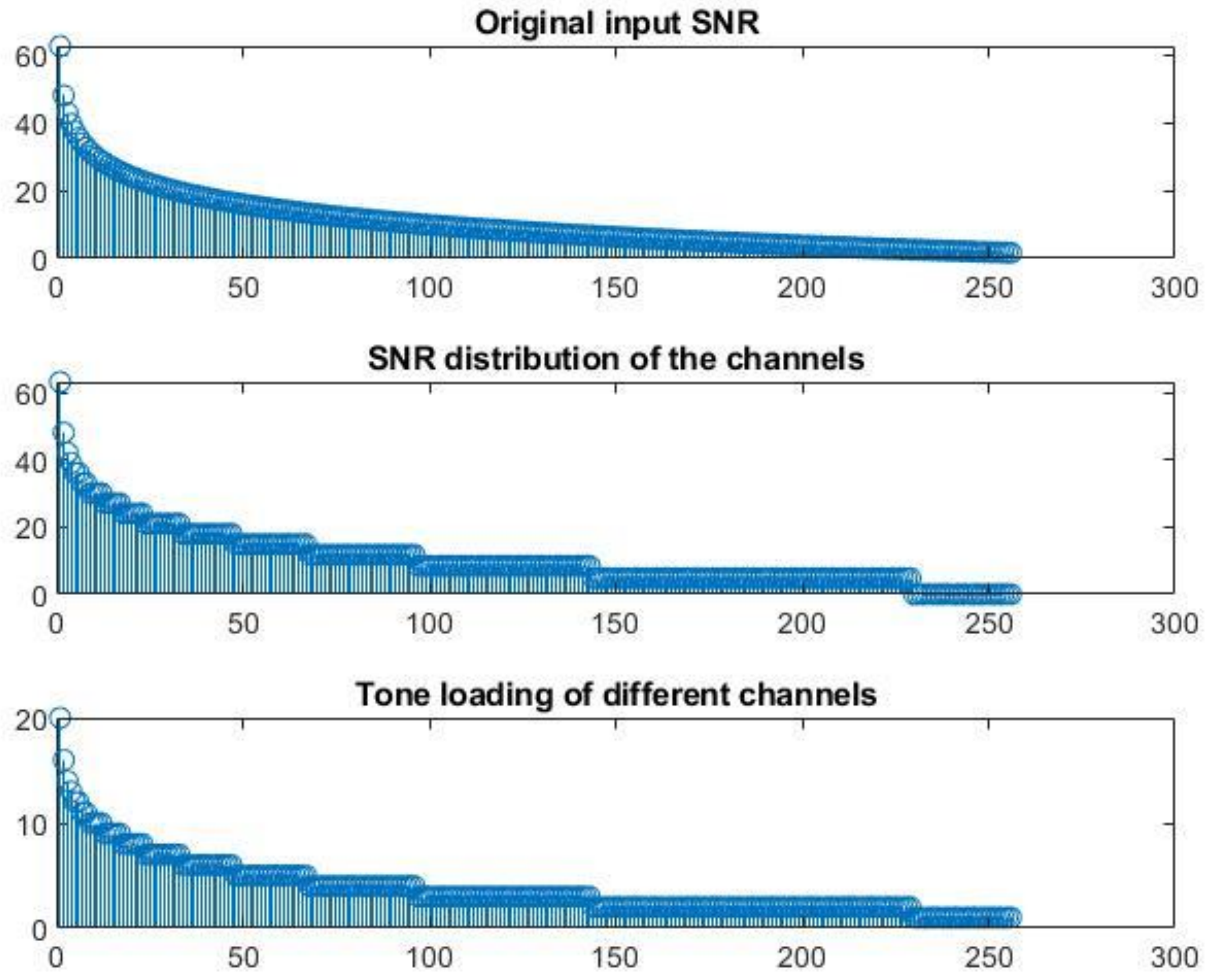


Inference:
Since there is only one antenna path to transmit 10^6 bits, there is a need of a total of 1643 cycles of transmitting bits as per the tone loading profile. Due to the lack of multiple antenna paths, it takes a long time to transmit the bits. To improve the speed (data rate), one must either improve the SNR of the channel to improve the channel capacity or go for MCM-MIMO system.

Results

SIMO System Results

```
Command Window
For noise power of -80 Hz/dBm The power deviation is -1.82
The bit error rate is 0
The number of cycles is 1051
fx >>
```



Inference:
To transmit 10^6 bits, one needs a total of 1051 cycles of transmitting bits as per the tone loading profile. This case is also known as receiver diversity, wherein one chooses the best path between the transmitter and receiver and use that path for the transmission of data. By periodically checking for the best path, it is possible to maintain a good quality link between transmitter and receiver that despite bad channel conditions.

Results

MISO System Results

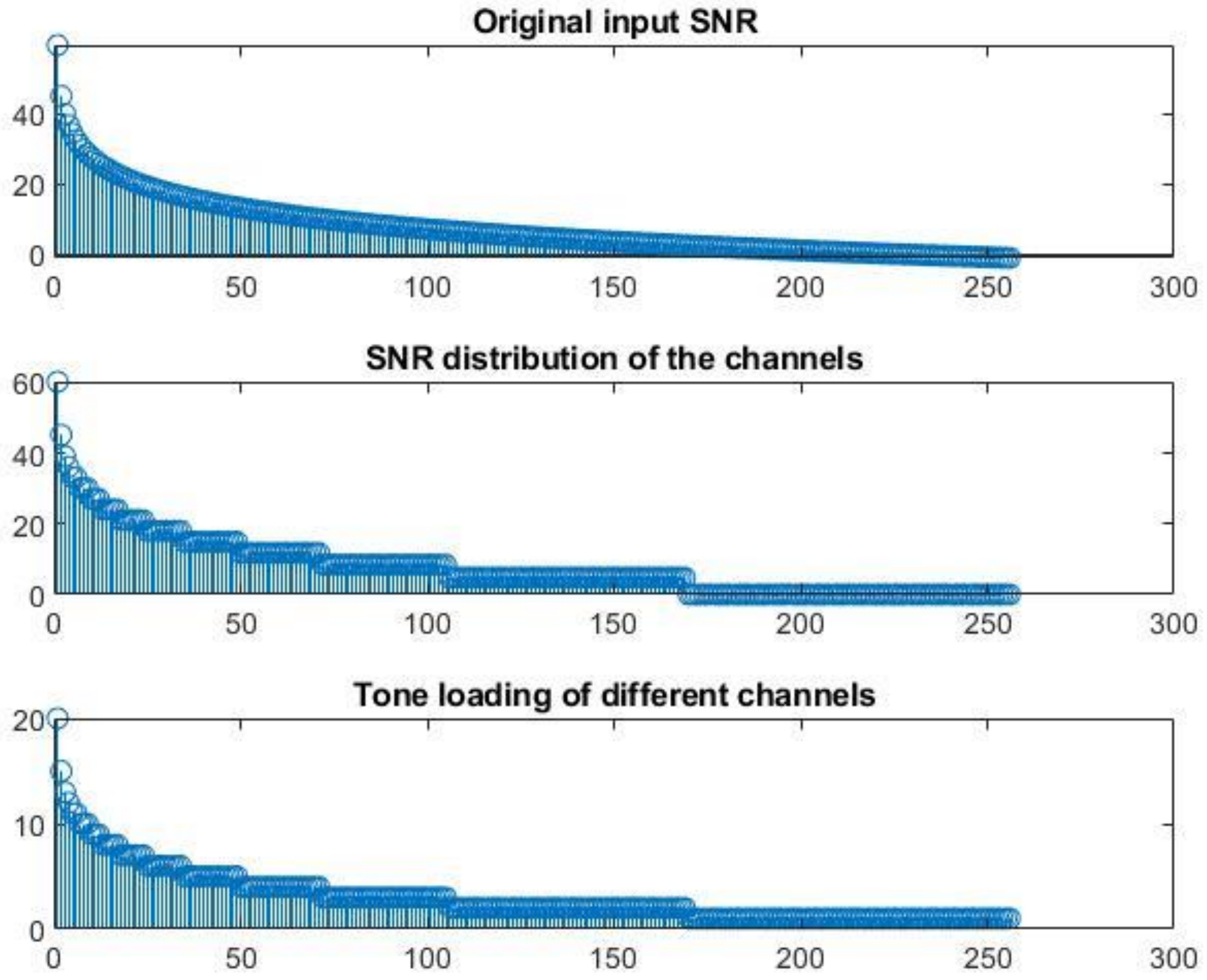
```
Command Window
The bit error rate is 0
The number of cycles is 196
fx >>
```

Inference:
It takes only 196 cycles to transmit the 10^6 bits. Since there are multiple transmitting antennas that use Alamouti coding, one is able to send 2 symbols in 2 time intervals, however with increase in the number of antennas the efficiency of the precoding falls.

Results

MIMO System Results- Diversity Case

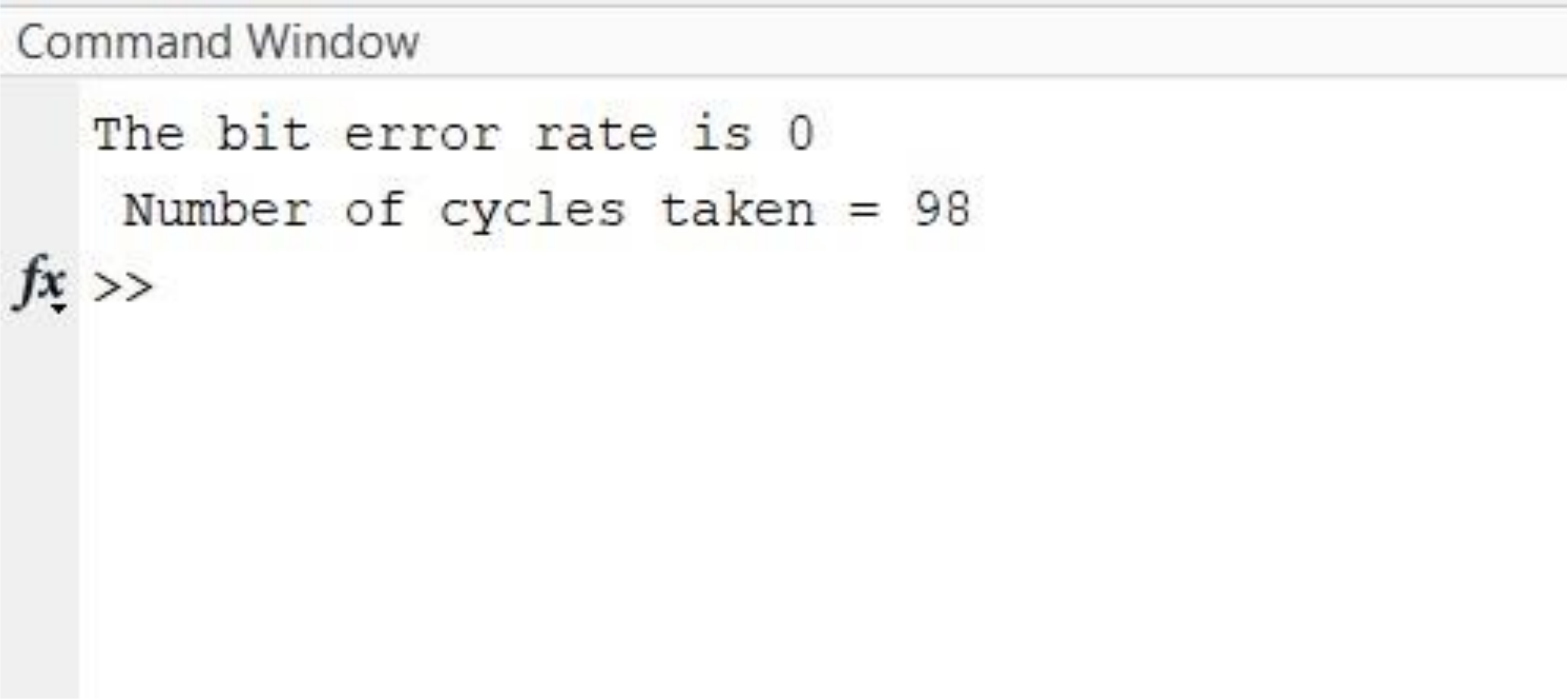
```
Command Window
For noise power of -80 Hz/dBm The power deviation is -1.3892
The bit error rate is 0
 Number of cycles taken = 1303
fx >>
```



Inference:
Although one has many antenna paths to transmit 10^6 bits, since one is operating in diversity mode, the system is only using the best channel between these two to transmit our data, hence one does not seeing much improvement in speed. It is seen how operating MIMO in multiplexing mode can vastly improve this system performance.

Results

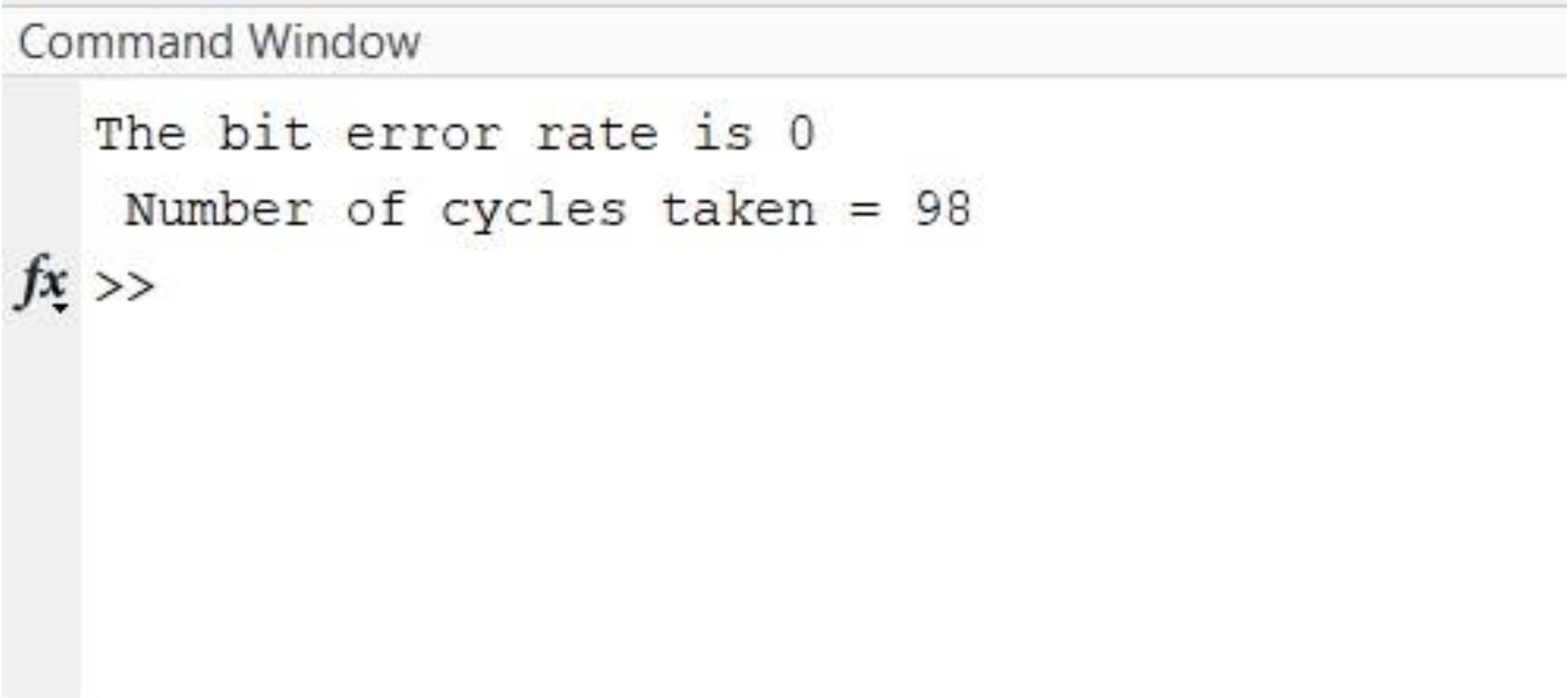
MIMO System Results-Multiplexing Case with ICE



Inference:
It takes only 98 cycles to transmit the 10^6 bits. One notices how by using suitable precoding the number of cycles reduce drastically. By using multiple antenna paths, data rates and capacities are vastly improved.

Results

MIMO System Results-Multiplexing Case with SVD



Inference:
Although the number of cycles taken for SVD decomposition is similar to that of Inverse Channel Estimation precoding, the speed of execution is noticed to be faster because it is computationally simpler to find the SVD of the matrix than to invert it. This is especially true when the size of the matrix is much larger than 2x2.

Timeline of the Project

Literature Survey
Sept 1

Alamouti coding
Sept 10

PRBS Generation and Constellation Mapping
Sept 13

QAM Demodulator
Sept 21

Fine gains Algorithm for bit loading
Oct 5th

Adaptive bit loading algorithm
Oct 26th

LOS function for SISO systems
Nov 13th

SISO, SIMO, MISO System Design
Nov 30th

MIMO System Design with SVD and ICE
Dec 17th

References

Sl No	Author, Title of paper, Journal	Year
1	Faouzi Bellili , Achref Methenni and Sofiene Affes, *" Closed - Form CLRBs for CFOs and Phase Estimation from Turbo Coded Square QAM Modulated Transmissions"*, **IEEE Transactions on Communications Technology, vol. 14, no. 5**	2015
2	Theodore S. Rappaport , George R. McCartney, Mathew K. Samimi and Shu Sun , *"Wideband Millimeter-Wave Propagation Measurements and Channel Models for Future Wireless Communication System Design"*, **International Transaction on Communications, vol. 63, no. 9**	2015
3	S B Weinstein and Paul M Ebert, *" Data Transmission by Frequency - Division Multiplexing Using Discrete Fourier Transform"*, **IEEE Transactions on Communications Technology, vol. 19, no. 5**	1971
4	Prateek Bansal and Andrew Brzezinski, *" Adaptive Loading in MIMO/OFDM Systems"*, **Semantic Scholar, Corpus ID : 29212466**	2001

References

Sl No	Author, Title of paper, Journal	Year
5	Peter S Chow, John M Cioffi and John A C Bingham , "*A Practical Discrete Multitone Transceiver Loading Algorithm for Data Transmission over Spectrally Shaped Channels*", **IEEE Transactions on Communications, vol. 43, no. 2/3/4**	1995
6	A Peinado and A Fuster-Sabater, " *Generation of Pseudorandon Binary Sequences by Means of Linear Feedback Shift Resistors (LFSRs) With Dynamic Feedback*", **Elesevier Journals on Mathematical and Computer Modelling**	2011
7	S M Alamouti , " *A simple transmit diversity technique for wireless communications* ", **IEEE Journal on Selected Areas in Communications, vol. 16, no. 8**	1998
8	Yiyan Wu and W Y Zou, " *Orthogonal frequency division multiplexing: a multi-carrier modulation scheme*", **IEEE Transactions on Communications, vol. 41, no.3**	1995

References

Sl No	Author, Title of paper, Journal	Year
9	Virginia C Klema and Alan J Laub, “*The Singular Value Decomposition: Its Computation and Some Applications*”, **IEEE Transactions on Automatic Control, vol. 25, no. 2**	1980
10	L Hanlen and M Fu, “ *Wireless communication systems with-spatial diversity: a volumetric model* ”, **IEEE Transactions on Wireless Communications, vol. 5, no. 1**	2006

Thank You