Visvesvaraya Technological University, Belagavi.

PROJECT REPORT

on

"ANALYSIS OF MIMO-OFDM USING NOMA"

Project Report submitted in partial fulfillment of the requirement for theaward of the degree of

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CERTIFICATE

This is to Certify that the dissertation work **"ANALYSIS OF MIMO-OFDM USING NOMA"**carried out byAISHWARYA R, CHANDANA M USN: 1CR16EC006, 1CR16EC030 BONAFIDE students of **CMRIT** in partial Fulfilment of the requirements for the degree of **Bachelor of Engineering**in**Electronics and Communication Engineering**of the**VISVESVARAYATechnological University, BELAGAVI,** during the academic year **2019-20**. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report deposited in the departmental library. Theproject report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said degree.

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CHAPTER 1

INTRODUCTION

Wireless communication is the electromagnetic transfer of information between two or more points that are connected by an electrical conductor. The most common wireless technologies use radio waves. Wireless communications can be via, Radio, Free-space optical, sonic, Electromagnetic induction. With radio waves, intended distances can be short, such as Bluetooth or as far as millions of kilometres for deep-space radio communications. It encompasses various types of fixed, mobile, and portable applications, including two-way radios, cellular telephones, personal digital assistants, and wireless networking.

In cellular mobile communications, the design of the radio access technology is one important aspect for improving system capacity in a cost-effective manner. Radio access technologies are typically characterised by radio frame design, waveform design, multiple input-multiple output transmission scheme, multiple access scheme. In particular, the design of the multiple access scheme is of great importance from a system perspective, since it provides the means for multiple users to access and share the system resources efficiently and simultaneously, e.g., frequency division multiple access(FDMA), time division multiple access(TDMA), code division multiple access(CDMA), and orthogonal frequency division multiple access(OFDMA).

1.1. AIM OF THE PROJECT

The main aim of this project is to analyse MIMO-OFDM with NOMA for better SNR-BER ratio. This technology has attracted a lot of attention as a novel and promising power-domain user multiplexing scheme for Long-Term Evolution enhancement and 5G.NOMA is a type of non-orthogonal multiplexing where users are multiplexed in the power domain, which is not sufficiently utilized by previous wireless mobile systems.

1.2. EVOLUTION OF WIRELESS COMMUNICATION TECHNOLOGY

a) 1G

1G refers to the first generation of wireless cellular technology. These are the analog telecommunications standards that were introduced in the 1980s and continued until begin replaced by 2G digital telecommunications, whereas 1G is only modulated to higher frequency, typically 150MHz and up. The inherent advantages of digital technology over that of analog meant that 2G networks eventually replaced them everywhere.

Disadvantage-1G makes use of analog rather than digital signals.

b) 2G

2G refers to the second generation of cellular network. Three primary benefits are

- Phone conversations were digitally encrypted.
- Significantly more efficient use of the radio frequency spectrum enabling more users per frequency band.
- Data services for mobile, starting with SMS text messages.

2G technologies enabled the various networks to provide the services such as text, messages, picture messages, and multimedia messages. All text messages sent over 2G are digitally encrypted, allowing the transfer of data in such a way that only the intended receiver can receive and read it. With General packet radio service (GPRS), 2G offers a theoretical maximum transfer speed of 40kbit/s. The most common 2G technology was the time division multiple access(TDMA)-based GSM.

c) 3G

3G refers to third generation of wireless mobile telecommunication technology. 3G finds application in wireless voice telephony, mobile internet access, fixed wireless internet access, video calls, and mobile TV. The communication spectrum between 400MHz to 3GHz was allocated. 3G telecommunication network support services that provides an information transfer rate of at least 144kbit/s. The first commercial 3G network were introduced in 2001. The technology used is code division multiple access. The disadvantage is power consumption is high.

d) 4G

4G refers to fourth generation of broadband cellular network, succeeding 3G. A 4G system must provide capabilities defined by ITU in IMT advanced. Potential and current applications include amended mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, and 3D television. The first-release Long term evolution standard was commercially deployed.

Disadvantage of 4G:

- In order to make and receive 4G voice calls, the subscriber handset must not only have a matching frequency band, it must also have the matching enablement settings for local carrier.
- A major issue in 4G systems is to make the high bit rates available in a larger portion of the cell, especially to users in an exposed position in between several base stations.

1.3. ROLE OF OFDM IN 4G

OFDM makes use of the concept of Orthoganality of signals and the properties of Discrete Fourier transform to transmit the signals whose spectrum can overlap with each other avoiding the use of guard band which was needed in traditional frequency division multiplexing technique. Since DFT is a linear combination of orthogonal sinusoids, it essentially correlates its input signal with each of the sinusoid basis function. So if the signal has some energy at certain frequency there will be a peak in the correlation of the input signal and the basis sinusoid that is at that corresponding frequency. This transform is utilized at the OFDM transmitter to map an input signal onto a set of orthogonal subcarrier side to process that is the orthogonal basis function of DFT. Again the transform is used at the receiver side to process the received subcarrier.

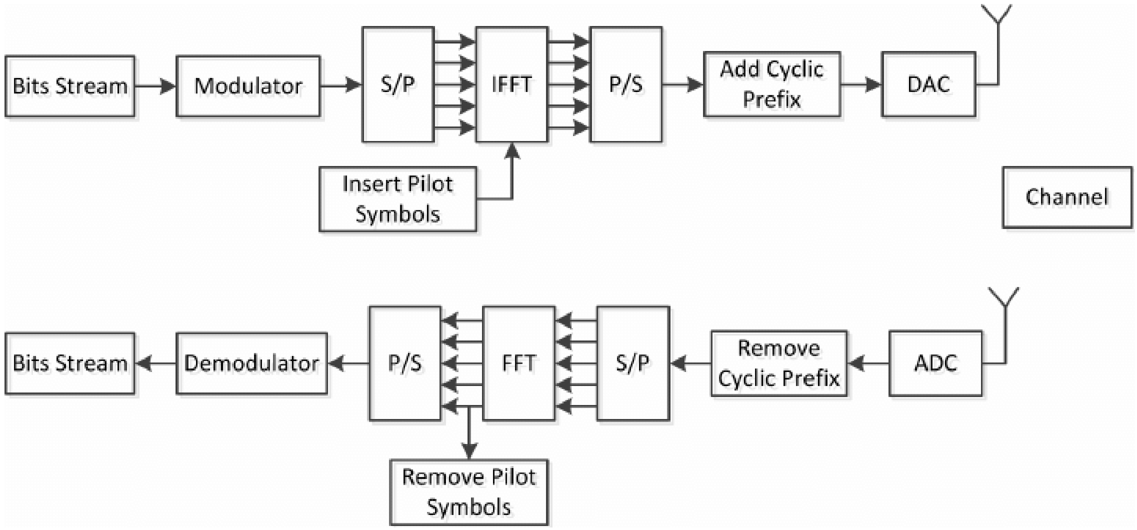

Fig 1: OFDM block diagram

1.3.1. ADVANTAGES

- Multi path distortion is eliminated.
- High spectral efficiency.
- Resiliency to RF spectrum.

1.3.2. DISADVANTAGES

- Impulse noise.
- Carrier interference.
- Local oscillator frequency offset.
- Local oscillator phase offset.
- FFT window location offset.

1.4. PROBLEM STATEMENT

Problems in OFDM systems are: Sensitive to phase noise, frequency offsets and timing errors Relatively high peak to average power ratio compared to single carrier system, which tends to reduce the power efficiency of the RF amplifier though the developments of OFDM technology, there are two considerable contributions to OFDM which transform the original Analog multicarrier system to today's digitally implemented OFDM. The modulation type 16QAM and 64QAM are clearly affecting the performance. In the case of AWGN channel the performance of single carrier and OFDM systems are comparable but the overall performance of the second one is higher having in mind that the OFDM systems achieve a higher capacity, coverage and reliability.

1.5. PROBLEM ANALYSIS

MIMO-OFDM is implemented along with NOMA, Non-Orthogonal Multiple Access (NOMA) is a multiple access method proposed for next generation (5G) mobile network. NOMA is a type of non-orthogonal multiplexing where users are multiplexed in the power domain, which is not sufficiently utilized by previous wireless mobile systems. Specifically, signals from different users are superposed at transmitter side and separated at receiver side by using successive interference cancellation (SIC).

Non-orthogonal Multiple Access and Massive MIMO for Improved Spectrum Efficiency

To cope with the expected 1000x increase in mobile traffic over the next 10 years, key requirements are making more efficient use of the available frequency spectrum, increasing network speeds and opening-up more of the frequency spectrum for wireless applications. OFDMA used by LTE, etc., is being extended and superposition of signals for multiple users using a new power domain are being investigated as methods for increasing spectrum efficiency. In addition, high-directivity adaptive antennas with 100 or more elements offering good compatibility with higher frequencies, interference suppression, and simultaneous multi-user access are other potential ways to improve spectrum efficiency. This paper examines 5G wireless access systems and outlines non-orthogonal access and MIMO technologies along with some issues to resolve.

1 - Introduction Next-generation 5G access systems are being investigated as a solution to the explosive increase (a factor of 1000x compared to 2010) in wireless data traffic forecast for the 2020s and the rapid appearance of various new services1,2). Three approaches are

being taken towards supporting these huge traffic increases: making more efficient use of available frequencies, increasing network speeds, and opening-up new frequency bands. Making more efficient use of available frequencies is closely related to speeding-up the physical layer for multi-access and wireless access technologies. For example, increases of from 2.5 to 10 times have been proposed as targets for increasing the efficiency of 5G frequencies3). Conventional mobile communications systems are moving towards faster digital wireless technologies based on advances in semiconductor devices as described below. The first generation (1G) used Frequency Division Multiple Access (FDMA), the second generation (2G) used Time Division Multiple Access (TDMA), the third generation (3G) is using Code Division Multiple Access (CDMA), and the 3.9G and fourth (4G) generations are using Orthogonal Frequency Division Multiple Access (OFDMA) supporting efficient frequency usage and good resistance to fading. The proposals for 5G systems aim to increase spectrum efficiency even further by speeding-up existing technologies, using newly opened frequency bands, and increasing network density, and support for the expected required conditions is being examined. The non-orthogonal multiple-access (NOMA) and higher-order multiple-input and multiple-output (MIMO) technologies described in this paper require huge processing power to implement these functions, which will be difficult to achieve using the performance of conventional semiconductor devices. Rapid developments in CPU processing power are expected to be a key element in deployment of 5G services. This paper describes the principles of each method related to these technologies and the problems to be resolved.

2 - Non-orthogonal Multiple Access (NOMA)

Multiple access is a basic function of cellular systems, which are usually divided into two types: orthogonal and non-orthogonal. In orthogonal access systems such as TDMA, FDMA, and OFDMA, signals for different users are orthogonal to each other. On the other hand, in non-orthogonal access systems, such as CDMA, TCMA (Trellis Coded Multiple Access), IDMA (Interleave Division Multiple Access)4), the cross-correlation of signals for different users is not 0. The commonly used NOMA incorporates the above-described non-orthogonal multiple access but this section discusses a specified NOMA implementation for

5G systems. NOMA under discussion for 5G systems has a new extension of the user multiplex domain to improve the spectrum efficiency. Intentionally introducing non-orthogonality aims to increase the spectrum efficiency further. As a result, technologies such as new encodings and an interference canceler are required to correct the non-orthogonality, which has been considered difficult to implement until now. However, development is pushing forward with the expectation of introduction as key 5G technology following recent remarkable improvements in CPU performance 5,6,7).

NOMA Schemes		
Method	Key Technologies	Superposition Domain
NOMA with SIC/SOMA	Interference Canceller, Coded bit Collection	Power (Symbol)
SCMA	Sparse Code	Power, Code
IDMA	Scrambling Code	Code

Table 1 lists the NOMA schemes. As shown, NOMA can be classified into three different user multiplex domains: NOMA with SIC (Successive Interference Canceler)/SOMA (Semi-orthogonal Multiple Access), SCMA (Sparse Code Multiple Access), and IDMA (Interleave Division Multiple Access). In addition to the conventional frequency and time domains, these schemes aim to increase the spectrum efficiency by multiplexing the user in the power domain for NOMA with SIC/SOMA, in the power and code domains for SCMA, and in the code domain for IDMA. The follow sections explain the characteristics and principles of each of these schemes.

2.1 NOMA with SIC/SOMA

NOMA with SIC (NOMA hereafter)/SOMA expands the radio resource allocation for the frequency and time domains used by LTE, etc. By superposing multiple user signals using the new power domain, it becomes possible to increase the spectrum efficiency even further and to increase the throughput. The NOMA and SOMA methods both make positive use of power and loss differences by modulation processing and multiplexing8,9,10,11)

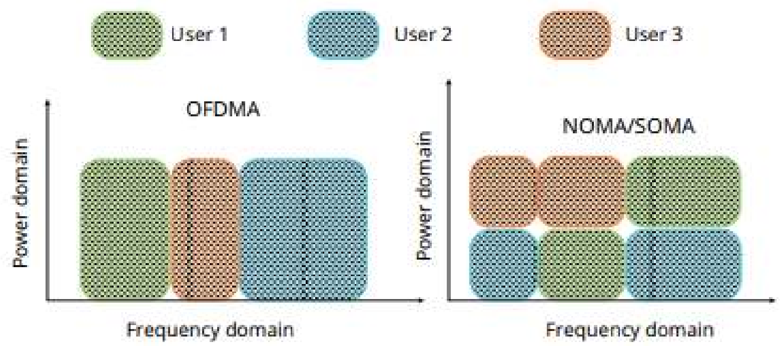

Figure 1: Image of NOMA/SOMA

Figure 1 shows an image of frequency usage. Multiple users in the power domain are superposed at the symbol level. This method uses SIC, turbo code, and Low Density Parity Check Code (LDPC) at the receiver side to separate superposed users.

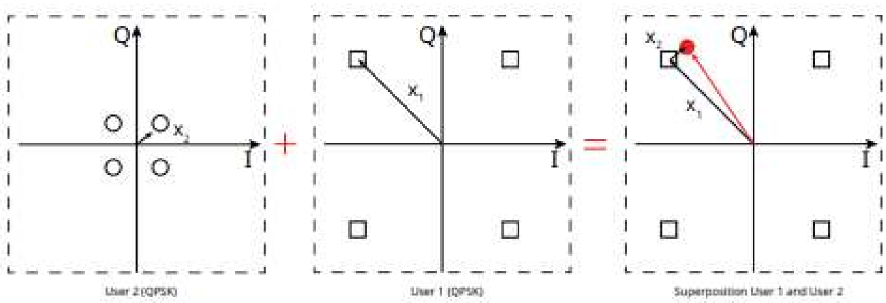

Figure 2: Superposition Encoding Example

Figure 2 shows an example of superposition coding where the User 2 Channel Gain h2 is better than the User 1 Channel Gain h1 . When using QPSK as the modulation method for each user, the symbol constellation after superposition approaches a constellation like that of 16QAM

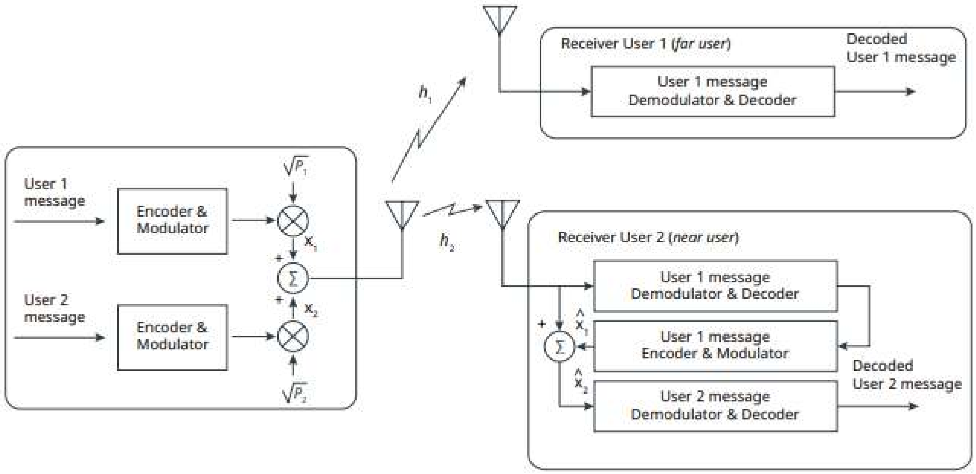

Figure 3: Basic NOMA Scheme Transmitter and Receivers in Downlink

Figure 3 shows a schematic diagram for a transmitter and receivers using NOMA. Since User 2 has better Channel gain than User 1 (in other words since the receiver environment is better), the original own signal is decoded after subtracting the effect of User 1 running SIC from the received signal. On the other hand, User 1 decodes its own signal by treating the User 2 signal as noise. The bit rate per 1 Hz for each user at this time (at superposition coding) is expressed by Eq. (1).

$$R_1 = log\left(1 + \frac{P_1\,|h_1|^2}{P_2\,|h_1|^2 + N_0}\right) \text{bits/s/Hz},$$

$$R_2 = log\left(1 + \frac{P_2\,|h_2|^2}{N_0}\right) \text{bits/s/Hz}$$

$$P_0 = P_1 + P_2,\ |h_2| > |h_1|,\ P_1 > P_2$$

User 2 with high channel gain is assigned the lower power P2 and the user with the low channel gain is assigned the higher power P1 to improve the average throughput for all users, resulting in improved spectrum efficiency. Figure 4 shows the throughput characteristics for both NOMA and Orthogonal Multiple Access (OMA) when there is a 20 dB difference in the receiver power levels; NOMA is characterized by an improvement of up to 2 bits/s/Hz compared to OMA.

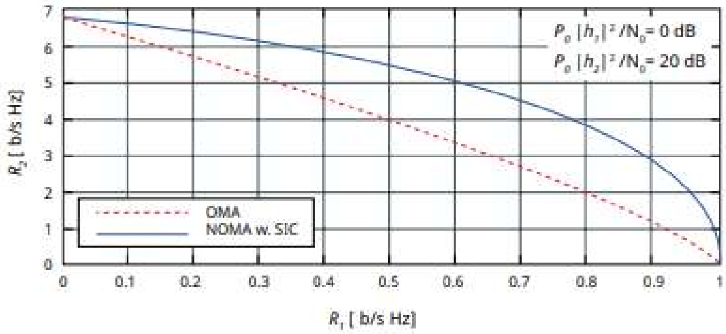

Figure 4: Downlink Throughput Region

The difference between NOMA and SOMA is the symbol constellation. The post-superposition symbol constellation mappings are divided into NOMA with SIC without Gray- Mapping and SOMA with GrayMapping. Both methods are now being investigated in 3GPP Release13 RAN1 TSG as a Multi User Superposition Transmitter (MUST). For simplicity these methods are commonly both described as NOMA. 2.2 SCMA SCMA is a relatively new wireless multi-access method proposed in 201312,13). It avoids the QAM symbol mapping used by conventional CDMA coding technologies and implements the binary data by coding it directly into multi-dimensional code words. Figure 5 shows the SCMA encoder block diagram. The figure shows a schematic of the SCMA encoder when there are four physical resources and four codewords in SCMA code book. Each user or layer assigns the binary data output from the FEC encoder directly to the complex codeword (physical resources dimensions) according to the predefined spreading code of the SCMA codebook

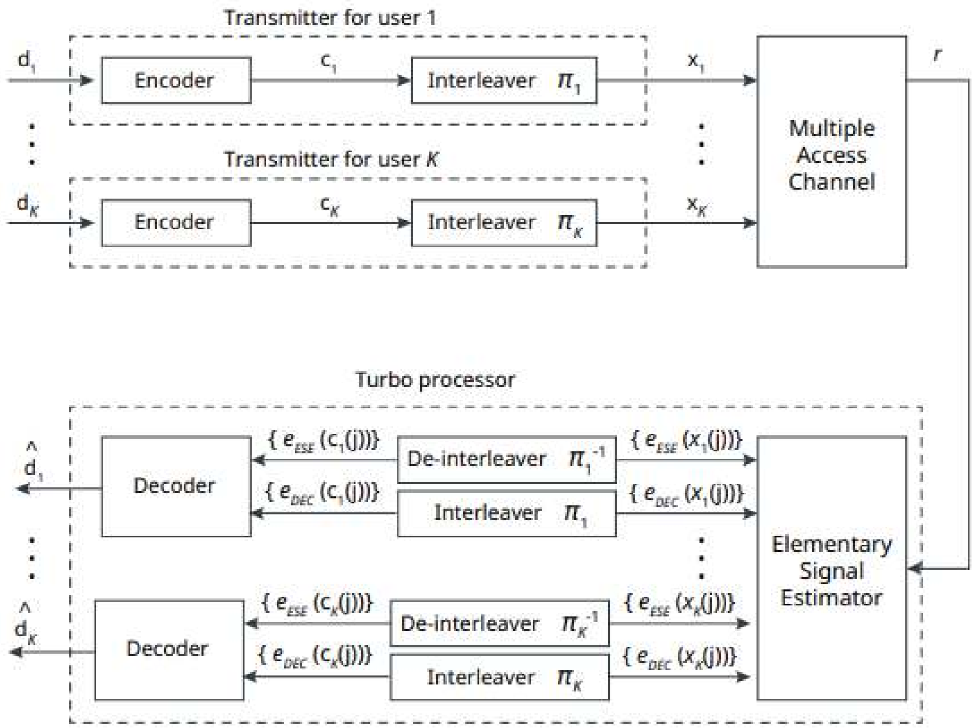

Figure 6: Transmitter and Receiver Structure of IDMA Scheme with K Users

shows the transmitter and receiver configuration. After coding, the information bit sequence is rearranged by using a user-specific interleaved pattern to generate the encoded transmission bit sequence, which is mapped to the modulation symbols. The IDMA receiver is a parallel-type repeat multi-user receiver composed of a multi-user interference canceler and decoder.

2.4 Issues in Measurement Development

As described so far, NOMA now under investigation for 5G has various methods. In particular, since the receiver performance depends directly on the SIC performance for NOMA, SOMA, and IDMA, measuring instruments must have functions for evaluating this performance correctly. However, there is presently no clear generation method for SCMA that includes codebook functions. Whether or not this can be solved either by standardization or by some implementation, development is pushing forward while watching trends in standardization and related technologies

MIMO Evolution

MIMO achieves high throughput and high reliability by using multiple antennas for transmitter and receiver (Figure 7) and it is a key technology in today's wireless communications systems. Furthermore, IEEE802.11ac and LTE-Advanced have adopted multi-user MIMO for simultaneous communications between base station with multiple antennas and multiple mobile terminals.

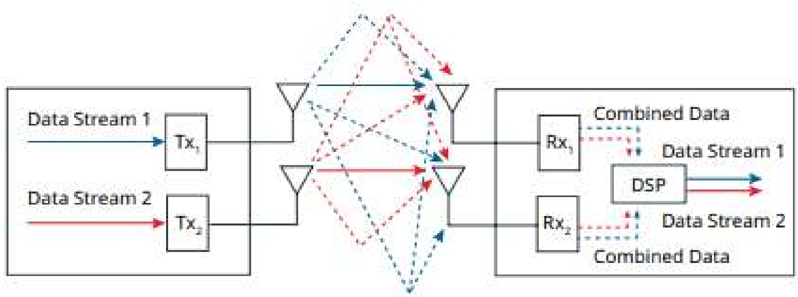

Figure 7: MIMO Principle

Currently, Massive-MIMO is being proposed as a new technology for improving MIMO characteristics, targeting the 5G roll out. Massive-MIMO uses up-ward of 100 antenna elements to support simultaneous communications with multiple mobile terminals, greatly improving the spectrum usage efficiency.

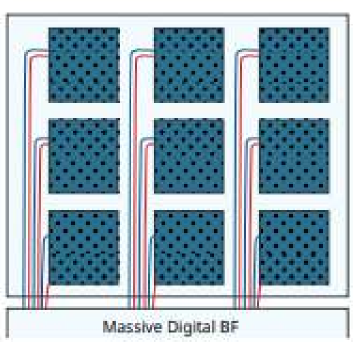

Figure 8: Massive-MIMO Configuration

In addition, use of higher frequency bands, such as the millimeter-wave band is being investigated for 5G16,17). Using the millimeter-wave band, is expected to support ultra-high-speed and largecapacity communications using small cells, but transmission losses are big in the higher frequency bands and become bigger especially at non-line-of-sight communications (NLOS). Data Stream 1 Data Stream 2 Data Stream 1 Data Stream 2 Combined Data Combined Data DSP Tx1 Tx2 Rx1 Rx2 Massive Digital BF アンリツテクニカル (8) 26 Non-orthogonal Multiple Access and Massive MIMO for Improved Spectrum Efficiency No. 91 Mar. 2016 Beam forming (BF) using Massive-MIMO antenna configurations (Figure 8) is thought to be effective in countering these increases in transmission losses. Since the antenna elements can be made small in proportion to the wavelength, the overall antenna size can be reduced even when using 100 or more antenna elements. Moreover, using Massive-MIMO can focus the energy to the mobile as a very tight beam, which not only improves the energy efficiency but is also expected to reduce interference between users. With 5G, in addition to conventional voice and internet services, video streaming, wireless Cloud, and M2M applications will become ubiquitous, re-quiring good service quality. In addition, these data communications will experience much higher variations in traffic levels with region and time, making it important to be able to accommodate bursts of user traffic in space and time.

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CHAPTER 2

LITERATURE SURVEY

Kala Praveen Bagadi estimated channel based on both block-type pilot and comb-type arrangements in both SISO and MIMO OFDM based systems are compared. Channel estimation based on comb-type pilot arrangement is achieved by giving the channel estimation methods at the pilot frequencies and the interpolation of the channel at data frequencies. The estimators in this study can be used to efficiently estimate the channel in both OFDM systems given certain knowledge about the channel statistics. The MMSE estimator assumes a priori knowledge of noise variance and channel co-variance. Then discussed space time block coding and maximum likelihood decoding in the MIMO OFDM system to enhance its performance further and can also observe the advantage of diversity in MIMO system results less BER than SISO system. And simulation results show that others systems. Finally, by comparing the performance of MMSE with LS, it is observed that the former is more resistant to the noise in terms of the channel estimation.

J. –J. van de Beek, O. Edfors, M. Sandell, S. K. Wilson, andP. O. Borjesson, estimated the channel in an OFDM system given a certain knowledge about the channel statistics. The MMSE estimator assumes a priori knowledge of noise variance and channel co-variance. Moreover, its complexity is large compared to LS estimator. For high SNRs the LS estimator is both simple and adequate. However, for low SNRs, the presented modifications of the MMSE and LS estimator will allow a compromise between estimator complexity and performance. For a 16QAM signalling, up to 4dB gain in SNR over the LS estimator was obtained, depending on estimator complexity. Even relative low-complex modified estimators, however, perform significantly better than the LS estimator for a range of SNRs.

Pan Pei-sheng, Zheng Bao-yu, proposed channel estimation method employs pilot structure in both space and frequency domain. By this method, different transmitting antennas can send pilot simultaneously and can perform estimation within one OFDM symbol. Optimality of this method in terms of MSE is verified. Simulation results show that, compared with the space time channel estimation method, the proposed method is more effective in fast fading environments. The simulation results indicate that OvCDM can significantly improve spectrum efficiency. However, as the spectrum efficiency and constrained length increase, the number of states increases exponentially. Consequently, the decoding complexity increases rapidly.

Athina Petropulu, R. Zhang, and R. Lin, Proposed a computationally simple approach for blind channel estimation in OFDM systems. At the transmitter, a simple pre-processing is performed at each block, which induces correlation structure to the block. This structure is exploited at the receiver to estimate the channel within a complex scalar. The proposed approach was shown to perform well with all modulation schemes tested here, and a wide range of SNRs. The proposed approach offers computational simplicity, and robustness.

Although it might appear that adding a constant to the block during the pre-coding step would result is a simpler channel estimation method, that would employ first order statistics of the received signal, such an approach would introduce a bias to each carrier. Such a bias is not desirable in practical system. The proposed pre-coding maintains the zero-mean of each carrier.

Higuchi K, Kishiyama Y, Proposed a new NOMA scheme utilizing CDM for downlink cellular systems. After PF-based scheduling, the subcarriers of the same user set are extracted, code-spread, and reallocated. In the receiver, CDM-based SIC is conducted. Numerical results show that an improved average user throughput was obtained because of the frequency diversity effect, particularly when the channel gains of the two superimposed users are significantly different. In addition an improved scheduling scheme, in which both the average user throughput and the fairness index were improved allowing a slight increase in the calculation complexity.

CHAPTER 3

SOFTWARE DESCRIPTION

Developed primarily by Cleve Moler in 1970’s.The name MATLAB stands for matrix laboratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects.

MATLAB is s high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports objectoriented programming. These factors make MATLAB an excellent tool for teaching and research.

MATLAB has many advantages compared to conventional languages for solving technical problems. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered as a standard tool at most universities and industries worldwide.

It has powerful built-in routines that enable a variety of computations. It also had easy to use graphics commands that make the visualisation of results immediately available. Specific applications are collected in packages referred to as toolbox. There are toolboxes for signal processing, symbolic computation, control theory, simulation, optimization and several other fields of applied science and engineering.

The MATLAB application is built around the MATLAB programming language. Common usage of the MATLAB application involves using "Command Window" as an interactive mathematical shell or executing text files containing MATLAB code.

MATLAB can call functions and subroutines written in the programming languages C or Fortran. A wrapper function is created allowing MATLAB data types to be passed and returned. MEX files (MATLAB executables) are the dynamically loadable object files created by compiling such functions. Since 2014 increasing two interfacing with python was being added. Many MATLAB libraries are implemented as wrappers around java or ActiveX libraries. Calling MATLAB from java is more complicated, but can be done with a MATLAB toolbox which is sold separately by mathworks, or using an undocumented mechanism called JMI(java-to-MATLAB interface). Official MATLAB API for java was added in 2016.MATLAB can be used as calculator.

MATLAB variables are created with an assignment statement. where expression is a combination of numerical values, mathematical operators, variables, and function calls. Once a variable has been created, it can be reassigned. If we enter an expression incorrectly, MATLAB will return an error message. MATLAB by default displays only 4 decimals in the result of the calculations. The command format controls how the results of computations are displayed. It is possible to keep track of everything done during a MATLAB session with the diary command.

MATLAB offers many predefined mathematical functions for technical computing which contains a large set of mathematical functions. There is a long list of mathematical functions that are built into MATLAB. These functions are called as built-ins. In addition to the elementary functions, MATLAB includes a number of predefined constant values.

MATLAB has an excellent set of graphic tools. Plotting a given data set or the results of computation is possible with very few commands. You are highly encouraged to plot mathematical functions and results of analysis as often as possible. Trying to understand mathematical equations with graphics is an enjoyable and very efficient way of learning mathematics. Being able to plot mathematical functions and data freely is the most important step. The plot function has different forms depending on the input arguments. MATLAB enables to add axis labels and titles. Multiplearguments create multiple graphs with a single call to plot. By default, MATLAB uses line style and colour to distinguish the data sets plotted in the graph. However, you can change the appearance of these graphic components or add annotations to the graph to help explain data for presentation. It is possible to specify line styles, colours, and markers using plot command.

Matrices are the basic elements of the MATLAB environment. A matrix is a two-dimensional array consisting of m rows and n columns. Special cases are column vectors and row vectors. MATLAB supports two types of operations, Known as matrix operations and array operations. Matrices are fundamentals to MATLAB. Therefore, we need to become familiar with matrix generation and manipulation. Matrices can be generated in several ways. A vector is a special case of a matrix. The elements of vectors in MATLAB are enclosed by square brackets and are separated by spaces or by commas. A matrix is an array of numbers. Once we have entered the matrix, it is automatically stored and remembered in the workspace. The colon operator will prove very useful and understanding how it works is the key to efficient and convenient usage of MATLAB. On the other hand, there is a command to generate linearly spaced vectors. To delete a row or column of a matrix, use the empty vector operator. To determine the dimensions of a matrix or vector, use the command size. If it is not possible to type the entire input on the same line, use consecutive periods, called as ellipsis, to signal continuation, then continue the input on the next line. MATLAB provides functions that generates elementary matrices and provides a number of special matrices.

One of the problems encountered most frequently in scientific computation is the solution of systems of simultaneous linear equations. MATLAB provides many matrix functions for various matrix manipulations. A script file is an external file that contains a sequence of MATLAB statements. The MATLAB editor is both a text-editor is both a text editor specialized for creating M-files and a graphical MATLAB debugger. The MATLAB editor has numerous menus for tasks such as saving, viewing, and debugging. Because it performs some simple checks and also uses colour to differentiate between various elements of codes, this text editor is recommended as the tool of choice for writing and editing M-files. Each M-file function has its own area of workspace, separated from the MATLAB base workspace.

The input arguments are listed inside parentheses following the function name. The output arguments are listed inside the brackets on the left side. They are used to transfer the output from the function file. When a script file is executed, the variables that are used in the calculations within the file must have assigned values. The assignment of a value to a variable can be done in three ways.

1. The variable is defined in the script file.

2. The variable is defined in the command prompt.
3. The variable is entered when the script is executed.

MATLAB automatically generates a display when commands are executed. In addition to this automatic display, MATLAB has several commands that can be used to generate displays or outputs.

MATLAB is also a programming language. Like other computer programming languages, MATLAB has some decision making structures for control of command execution. These decision making or control flow structures include for loop, while loops, and if-else-end constructions. Control flow structures are often used in script M-filed and function M-files. By creating a file with the extension .m, we can easily write and run program, we do not need to compile the program since MATLAB is an interpretative language. MATLAB has thousand of functions, and you can add your own using m-files. MATLAB provides several tools that can be used to control the flow of a program. The commands are executed one after the other. Here we introduce the flow control structure that make possible to skip commands or to execute specific group of commands. MATLAB has four control flow structures,thefor loop, the while loop, and the switch statement.

In addition to displaying output on the screen, the command fprintf canbe used for writing the output to a file. The saved data can subsequently be used by MATLAB or other software. Debugging is the process by which can isolate and fix errors in your program or code. We can debug the M-files using the editor/debugger as well as using debugging functions from the command window. Set breakpoints to pause execution of the function, so we can examine where the problem might be.After setting breakpoints, run the M-files from the Editor/Debugger or from the command window.

While the program is paused, we can view the value of any variable currently in the workspace. Examine values when we want to see whether a line of code has produced the expected result or not. If the result is an expected, step to the next line, and continue running. If the result is not as expected, them that line, or the previous line, contain an error. When we run a program, the current workspace is shown in the stack field. Use who and or whos to list the variables in the current workspace. While debugging, we can change the value of a variable to see if the new value produces expected results. While the program is paused, assign a new value to the variable in the command window, workspace browser, or array editor. Then continue running and stepping through the program.

3.1.FEATURES OF MATLAB

- It is a high-level language for numerical computation, visualization and application development.
- It also provides an interactive environment for iterative exploration, design and problem solving.

- It provides vast library of mathematical functions for linear algebra, statics, Fourier analysis, filtering, optimization, numerical integration and solving ordinary differential equations.
- It provides built-in graphics for visualizing data and tools for creating custom plots.
- MATLAB's programming interface gives development tools for improving code quality maintainability and maximizing performance.
- It provides tools for building applications with custom graphical interfaces.
- It provides functions for integrating MATLAB based algorithms with external applications and languages such as C, Java, .NET and Microsoft Excel.

3.2. USES OF MATLAB

MATLAB is widely used as a computational tool in science and engineering encompassing the fields of physics, chemistry, math and all engineering streams. It is used in a range of applications including-

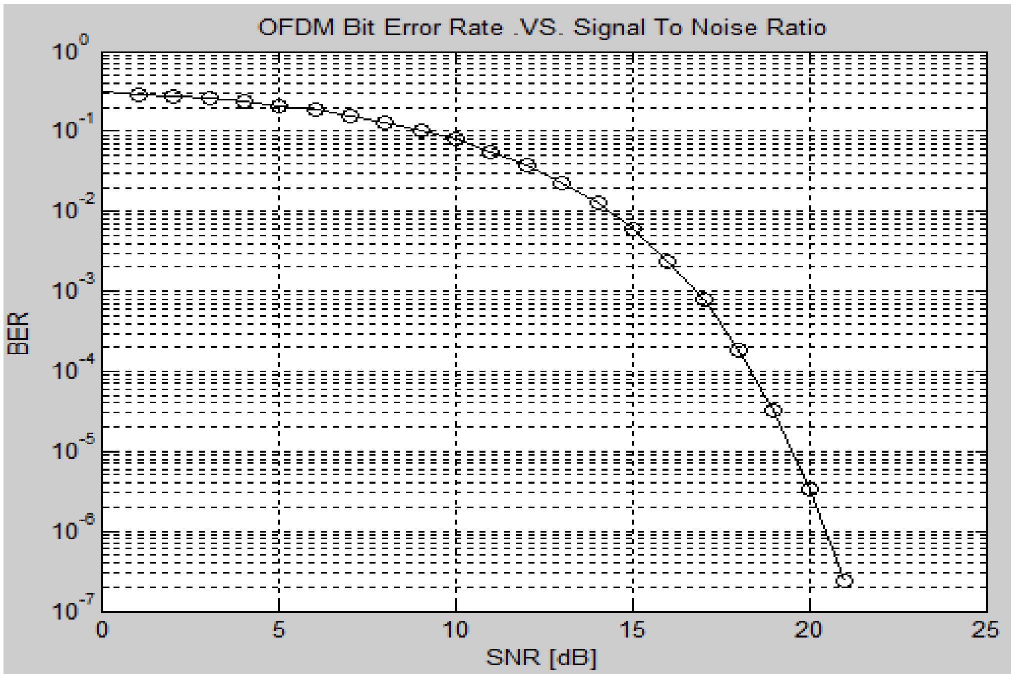
- Signal processing and communications
- Image and video processing
- Control systems
- Test and measurement
- Computational finance
- Computational biology

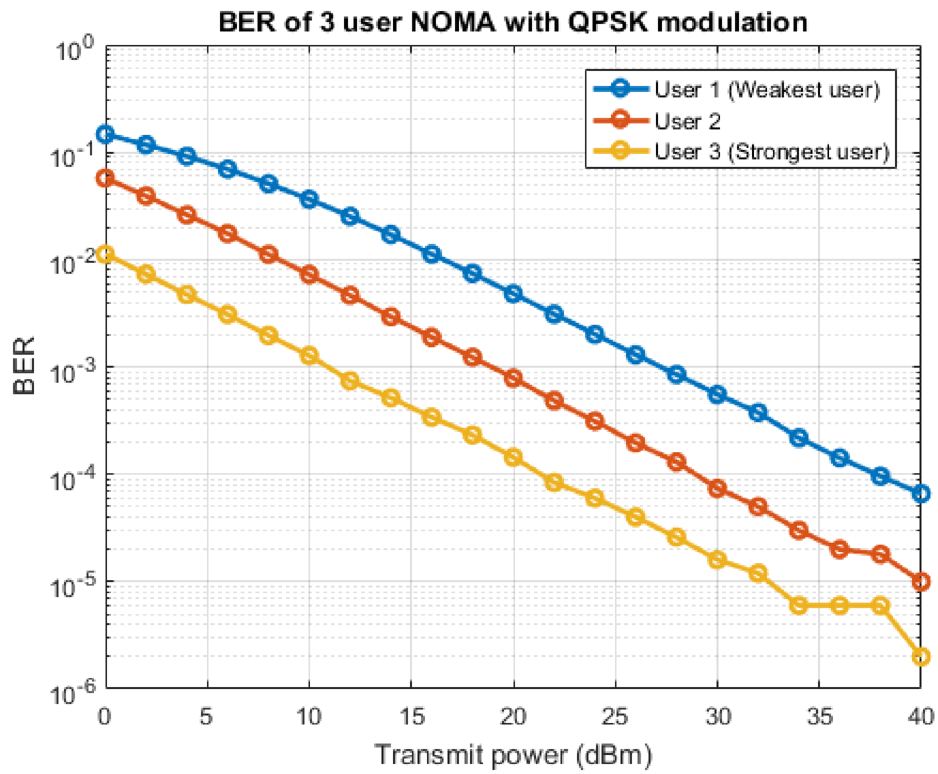
CHAPTER 4

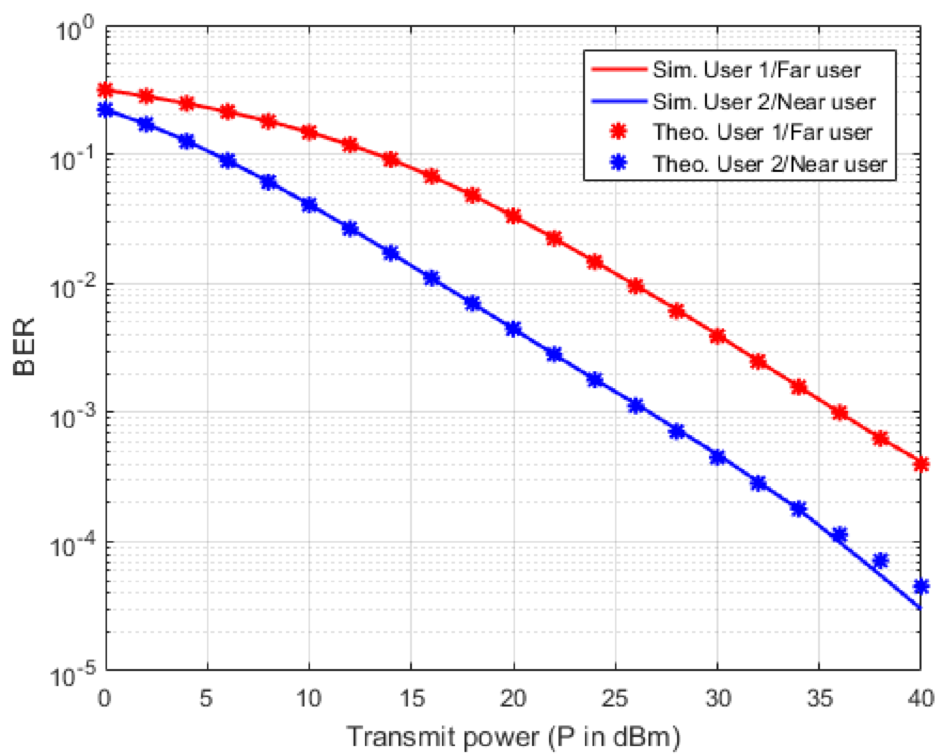
RESULTS

In digital transmission, the number of bit errors is the number of received bits of data stream over a communication channel have been altered due to noise, interference, distortion or bit synchronization errors. The bit error rate is the number of bit errors per unit time. The bit error ratio is the number of bit errors divided by the total number of transferred bits during a studied time interval. Bit error ratio is a unit-less performance measure, often expressed as percentage.

The BER performance of simple OFDM systems over AWGN channel is better than those of simple OFDM systems over Rayleigh fading channel. However, with the inclusion of the MIMO system the BER performance of both modulation schemes over the Rayleigh fading channel improves even better than that of a simple OFDM system over AWGN channel.




BER of 3 user NOMA with QPSK modulation
User 1 (Weakest user)
User 2
User 3 (Strongest user)
BER
Transmit power (dBm)


Sim. User 1/Far user
Sim. User 2/Near user
Theo. User 1/Far user
Theo. User 2/Near user
BER
Transmit power (P in dBm)

CHAPTER 5

ADVANTAGES AND DISADVANTAGES

5.1. ADVANTAGES

- It offers higher spectral efficiency due to use of multiple users on same frequency resource.
- It offers massive connectivity by serving more uses simultaneously at the same time.
- It offers lower latency due to simultaneous transmission all the time rather than dedicated scheduled time slot.
- It offers better QoS to all the users using flexible power control algorithms. It helps in increasing cell-edge throughput and better user experience at cell-edges.
- The NOMA along with MIMO delivers enhanced performance.

5.2. DISADVANTAGES

- Each of the users within the cluster need to decode information of all the other users even one having worst channel gains. This leads to complexity in the receiver. Moreover energy consumption is higher.
- If error occurs in single user due to SIC, decoding of all the other users information will be erroneous. This limits maximum number of users to be served by each of the clusters of the cell.
- In order to achieve desired functionalities of power domain concept in NOMA at the receiver, channel gain difference between users should be adequate. This limits effective number user pairs served by clusters.
- Each users required to provide channel gain information back to base station as feedback and hence NOMA is sensitive enough to obtain these measurements.

CHAPTER 6

APPLICATIONS

- NOMA with MIMO and MASSIVE MIMO.
- DEVICE to DEVICE NOMA.
- Cooperative NOMA.
- NOMA and OMA performance Analysis in Non-Cooperative phase.
- NOMA in Cognitive Radio Networks.
- RF Energy Harvesting Assisted NOMA.

CHAPTER 7

CONCLUSION

Different from OFDMA, NOMA superposes multiple users in the power-domain, exploiting the channel gain difference between multiple UEs. NOMA contributes to the maximization of the trade of between system performance and user fairness. NOMA involves several aspects that need careful design, including the granularity in time and frequency of multi-user scheduling and multi-user power allocation, signalling overhead, receiver design, and combination with MIMO. NOMA can also be applied to uplink. For uplink, new issues arise including power control design to balance inter-cell and intra-cell interference and the design of the scheduling algorithm in case of single carrier transmission. From performance perspective, NOMA has shown promising gains for both downlink and uplink. Moreover, gains are expected to increase with more users.

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APPENDIX

OFDM with MIMO for 2*2 or 2*1 or 4*3 or 8*8

```
qpskMod = comm.QPSKModulator;
qpskDemod = comm.QPSKDemodulator;
```

```
ofdmMod =
comm.OFDMModulator('FFTLength',128,'PilotInputPort',true,...
'PilotCarrierIndices',cat(3,[12; 40; 54; 76; 90; 118],...
    [13; 39; 55; 75; 91; 117]),'InsertDCNull',true,...
'NumTransmitAntennas',2);
ofdmDemod = comm.OFDMDemodulator(ofdmMod);
ofdmDemod.NumReceiveAntennas = 2;
```

```
showResourceMapping(ofdmMod)
```

```
ofdmModDim = info(ofdmMod);


numData = ofdmModDim.DataInputSize(1);   % Number of data
subcarriers
numSym = ofdmModDim.DataInputSize(2);    % Number of OFDM symbols
numTxAnt = ofdmModDim.DataInputSize(3);  % Number of transmit
antennas
```

Generate data symbols to fill 100 OFDM frames.

```
nframes = 100;
data = randi([0 3],nframes*numData,numSym,numTxAnt);
```

Apply QPSK modulation to the random symbols and reshape the resulting column vector to match the OFDM modulator requirements.

```
modData = qpskMod(data(:));
modData = reshape(modData,nframes*numData,numSym,numTxAnt);
```

Create an error rate counter.

```
errorRate = comm.ErrorRate;
```

.

```
for k = 1:nframes
```

```
% Find row indices for kth OFDM frame
    indData = (k-1)*ofdmModDim.DataInputSize(1)+1:k*numData;

% Generate random OFDM pilot symbols
    pilotData = complex(rand(ofdmModDim.PilotInputSize), ...
        rand(ofdmModDim.PilotInputSize));

% Modulate QPSK symbols using OFDM
    dataOFDM = ofdmMod(modData(indData,:,:),pilotData);

% Create flat, i.i.d., Rayleigh fading channel
    chGain = complex(randn(2,2),randn(2,2))/sqrt(2); % Random 2x2
channel change for other input here

% Pass OFDM signal through Rayleigh and AWGN channels
    receivedSignal = awgn(dataOFDM*chGain,30);

% Apply least squares solution to remove effects of fading
channel
    rxSigMF = chGain.' \ receivedSignal.';

% Demodulate OFDM data
    receivedOFDMData = ofdmDemod(rxSigMF.');

% Demodulate QPSK data
    receivedData = qpskDemod(receivedOFDMData(:));

% Compute error statistics
    dataTmp = data(indData,:,:);
    errors = errorRate(dataTmp(:),receivedData);
end
```

```
fprintf('\nSymbol error rate = %d from %d errors in %d
symbols\n',errors)
```

FOR 2*1 CHANNEL

```
Symbol error rate = 4.559615e-01 from 9484 errors in 20800
symbols
```

FOR 2*2 CHANNEL

```
Symbol error rate = 1.130288e-01 from 2351 errors in 20800
symbols
```

BER VS SNR GRAPHS

```
close all
clear all
clc
%%
% Generating and coding data
t_data=randint(9600,1)';
x=1;
si=1; %for BER rows
%%
for d=1:100;
data=t_data(x:x+95);
x=x+96;
k=3;
n=6;
s1=size(data,2);  % Size of input matrix
j=s1/k;
%%
% Convolutionally encoding data
constlen=7;
codegen = [171 133];    % Polynomial
trellis = poly2trellis(constlen, codegen);
codedata = convenc(data, trellis);
%%
%Interleaving coded data
s2=size(codedata,2);
j=s2/4;
matrix=reshape(codedata,j,4);
intlvddata = matintrlv(matrix',2,2)'; % Interleave.
intlvddata=intlvddata';
%%
% Binary to decimal conversion
dec=bi2de(intlvddata','left-msb');
%%
%16-QAM Modulation
M=16;
y = qammod(dec,M);
% scatterplot(y);
%%
```

```
% Pilot insertion
lendata=length(y);
pilt=3+3j;
nofpits=4;
k=1;
for i=(1:13:52)

    pilt_data1(i)=pilt;
for j=(i+1:i+12);
        pilt_data1(j)=y(k);
        k=k+1;
end
end
pilt_data1=pilt_data1';   % size of pilt_data =52
pilt_data(1:52)=pilt_data1(1:52);    % upsizing to 64
pilt_data(13:64)=pilt_data1(1:52);   % upsizing to 64
for i=1:52

    pilt_data(i+6)=pilt_data1(i);

end
%%
% IFFT
ifft_sig=ifft(pilt_data',64);
%%
% Adding Cyclic Extension
cext_data=zeros(80,1);
cext_data(1:16)=ifft_sig(49:64);
for i=1:64

    cext_data(i+16)=ifft_sig(i);

end
%%
% Channel
% SNR
 o=1;
for snr=0:2:50
ofdm_sig=awgn(cext_data,snr,'measured'); % Adding white Gaussian
Noise
% figure;
% index=1:80;
% plot(index,cext_data,'b',index,ofdm_sig,'r'); %plot both
signals
% legend('Original Signal to be Transmitted','Signal with AWGN');
%%
%                   RECEIVER
%%
%Removing Cyclic Extension
for i=1:64
```

```
    rxed_sig(i)=ofdm_sig(i+16);

end
%%
% FFT
ff_sig=fft(rxed_sig,64);
%%
% Pilot Synch%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for i=1:52

    synched_sig1(i)=ff_sig(i+6);

end
k=1;
for i=(1:13:52)

for j=(i+1:i+12);
        synched_sig(k)=synched_sig1(j);
        k=k+1;
end
end
% scatterplot(synched_sig)
%%
% Demodulation
dem_data= qamdemod(synched_sig,16);
%%
% Decimal to binary conversion
bin=de2bi(dem_data','left-msb');
bin=bin';
%%
% De-Interleaving
deintlvddata = matdeintrlv(bin,2,2); % De-Interleave
deintlvddata=deintlvddata';
deintlvddata=deintlvddata(:)';
%%
%Decoding data
n=6;
k=3;
decodedata =vitdec(deintlvddata,trellis,5,'trunc','hard');  %
decoding datausing veterbi decoder
rxed_data=decodedata;
%%
% Calculating BER
rxed_data=rxed_data(:)';
errors=0;
c=xor(data,rxed_data);
errors=nnz(c);
% for i=1:length(data)
%
%
%     if rxed_data(i)~=data(i);
```

```
%          errors=errors+1;
%
%      end
% end
BER(si,o)=errors/length(data);
o=o+1;
end % SNR loop ends here
 si=si+1;
end % main data loop
%%
% Time averaging for optimum results
for col=1:25;         %%%change if SNR loop Changed
    ber(1,col)=0;
for row=1:100;


        ber(1,col)=ber(1,col)+BER(row,col);
end
end
ber=ber./100;
%%
figure
i=0:2:48;
semilogy(i,ber);
title('BER vs SNR');
ylabel('BER');
xlabel('SNR (dB)');
grid on
```

NOMA

```
clc; clear variables; close all;

N = 5*10^5;

Pt = 0:2:40;                    %Transmit power (dBm)

pt = (10^-3)*db2pow(Pt);%Transmit power (linear scale)

BW = 10^6;                      %Bandwidth = 1 MHz

No = -174 + 10*log10(BW);       %Noise power (dBm)              %

no = (10^-3)*db2pow(No);        %Noise power (linear scale)

d1 = 500; d2 = 200; d3 = 70;    %Distances

a1 = 0.8; a2 = 0.15; a3 = 0.05; %Power allocation coefficients

eta = 4;     %Path loss exponent


%Generate Rayleigh fading channel for the three users

h1 = sqrt(d1^-eta)*(randn(N/2,1) + 1i*randn(N/2,1))/sqrt(2);

h2 = sqrt(d2^-eta)*(randn(N/2,1) + 1i*randn(N/2,1))/sqrt(2);

h3 = sqrt(d3^-eta)*(randn(N/2,1) + 1i*randn(N/2,1))/sqrt(2);


%Generate noise samples for the three users

n1 = sqrt(no)*(randn(N/2,1) + 1i*randn(N/2,1))/sqrt(2);

n2 = sqrt(no)*(randn(N/2,1) + 1i*randn(N/2,1))/sqrt(2);

n3 = sqrt(no)*(randn(N/2,1) + 1i*randn(N/2,1))/sqrt(2);


%Generate random binary message data for the three users

x1 = randi([0 1],N,1);

x2 = randi([0 1],N,1);

x3 = randi([0 1],N,1);
```

```
%Create QPSKModulator and QPSKDemodulator objects
QPSKmod = comm.QPSKModulator('BitInput',true);
QPSKdemod = comm.QPSKDemodulator('BitOutput',true);

%Perform QPSK modulation
xmod1 = step(QPSKmod, x1);
xmod2 = step(QPSKmod, x2);
xmod3 = step(QPSKmod, x3);

%Do super position coding
x = sqrt(a1)*xmod1 + sqrt(a2)*xmod2 + sqrt(a3)*xmod3;
for u = 1:length(Pt)

%Received signals
  y1 = sqrt(pt(u))*x.*h1 + n1;     %At user 1
  y2 = sqrt(pt(u))*x.*h2 + n2;     %At user 2
  y3 = sqrt(pt(u))*x.*h3 + n3;     %At user 3

%Perform equalization
  eq1 = y1./h1;
  eq2 = y2./h2;
  eq3 = y3./h3;

%Decode at user 1 (Direct decoding)
  dec1 = step(QPSKdemod, eq1);
```

%Decode at user 2

```
dec12 = step(QPSKdemod, eq2);%Direct demodulation to get U1's data
  dec12_remod = step(QPSKmod, dec12);%Remodulation of U1's data
  rem2 = eq2 - sqrt(a1*pt(u))*dec12_remod;%SIC to remove U1's data
dec2 = step(QPSKdemod, rem2);%Direct demodulation of remaining signal
```

%Decode at user 3

```
 dec13 = step(QPSKdemod, eq3);           %Direct demodulation to get U1's data
dec13_remod = step(QPSKmod, dec13);%Remodulation of U1's data
 rem31 = eq3 - sqrt(a1*pt(u))*dec12_remod;   %SIC to remove U1's data
 dec23 = step(QPSKdemod, rem31);%Direct demodulation of remaining signal
to get U2's data
dec23_remod = step(QPSKmod, dec23);%Remodulation of U2's data
 rem3 = rem31 - sqrt(a2*pt(u))*dec23_remod;          %SIC to remove U2's data
 dec3 = step(QPSKdemod, rem3);%Demodulate remaining signal to get U3's
data
```

%BER calculation

```
  ber1(u) = biterr(dec1, x1)/N;
  ber2(u) = biterr(dec2, x2)/N;
  ber3(u) = biterr(dec3, x3)/N;
end
semilogy(Pt, ber1, '-o', 'linewidth', 2); hold on; grid on;
semilogy(Pt, ber2, '-o', 'linewidth', 2);
semilogy(Pt, ber3, '-o', 'linewidth', 2);
xlabel('Transmit power (dBm)');
ylabel('BER');
legend('User 1 (Weakest user)', 'User 2', 'User 3 (Strongest user)');
```

BER VS SNR OF NOMA

```
clc; clear variables; close all;
N = 10^6;
d1 = 1000; d2 = 500;   %Distances of users from base station (BS)
a1 = 0.75; a2 = 0.25;   %Power allocation factors
eta = 4;               %Path loss exponent

%Generate rayleigh fading coefficient for both users
h1 = sqrt(d1^-eta)*(randn(1,N)+1i*randn(1,N))/sqrt(2);
h2 = sqrt(d2^-eta)*(randn(1,N)+1i*randn(1,N))/sqrt(2);
g1 = (abs(h1)).^2;
g2 = (abs(h2)).^2;
Pt = 0:2:40;              %Transmit power in dBm
pt = (10^-3)*10.^(Pt/10);   %Transmit power in linear scale
BW = 10^6;                %System bandwidth
No = -174 + 10*log10(BW);   %Noise power (dBm)
no = (10^-3)*10.^(No/10);   %Noise power (linear scale)

%Generate noise samples for both users
w1 = sqrt(no)*(randn(1,N)+1i*randn(1,N))/sqrt(2);
w2 = sqrt(no)*(randn(1,N)+1i*randn(1,N))/sqrt(2);

%Generate random binary data for two users
data1 = randi([0 1],1,N);  %Data bits of user 1
data2 = randi([0 1],1,N);  %Data bits of user 2
```

```
%Do BPSK modulation of data
x1 = 2*data1 - 1;
x2 = 2*data2 - 1;
p = length(Pt);
for u = 1:p

 %Do superposition coding
x = sqrt(pt(u))*(sqrt(a1)*x1 + sqrt(a2)*x2);

%Received signals
   y1 = h1.*x + w1;
   y2 = h2.*x + w2;

    %Equalize
   eq1 = y1./h1;
   eq2 = y2./h2;

    %AT USER 1--------------------
    %Direct decoding of x1 from y1
   x1_hat = zeros(1,N);
   x1_hat(eq1>0) = 1;

    %Compare decoded x1_hat with data1 to estimate BER
   ber1(u) = biterr(data1,x1_hat)/N;
```

```
%AT USER 2------------------------

%Direct decoding of x1 from y2

x12_hat = ones(1,N);

x12_hat(eq2<0) = -1;

y2_dash = eq2 - sqrt(a1*pt(u))*x12_hat;

x2_hat = zeros(1,N);

x2_hat(real(y2_dash)>0) = 1;


ber2(u) = biterr(x2_hat, data2)/N;

%---------------------------------


gam_a = 2*((sqrt(a1*pt(u))-sqrt(a2*pt(u)))^2)*mean(g1)/no;

gam_b = 2*((sqrt(a1*pt(u))+sqrt(a2*pt(u)))^2)*mean(g1)/no;

ber_th1(u) = 0.25*(2 - sqrt(gam_a/(2+gam_a)) - sqrt(gam_b/(2+gam_b)));


gam_c = 2*a2*pt(u)*mean(g2)/no;

gam_d = 2*((sqrt(a2) + sqrt(a1))^2)*pt(u)*mean(g2)/no;

gam_e = 2*((sqrt(a2) + 2*sqrt(a1))^2)*pt(u)*mean(g2)/no;

gam_f = 2*((-sqrt(a2) + sqrt(a1))^2)*pt(u)*mean(g2)/no;

gam_g = 2*((-sqrt(a2) + 2*sqrt(a1))^2)*pt(u)*mean(g2)/no;


gc = (1 - sqrt(gam_c/(2+gam_c)));

gd = (1-sqrt(gam_d/(2+gam_d)));

ge = (1-sqrt(gam_e/(2+gam_e)));

gf = (1-sqrt(gam_f/(2+gam_f)));

gg = (1-sqrt(gam_g/(2+gam_g)));


ber_th2(u) = 0.5*gc - 0.25*gd + 0.25*(ge+gf-gg);
```

```
  gamma1(u) = a1*pt(u)*mean(g1)/(a2*pt(u)*mean(g1) + no);
  gamma2(u) = a2*pt(u)*mean(g2)/no;
end

semilogy(Pt, ber1,'r', 'linewidth',1.5); hold on; grid on;
semilogy(Pt, ber2,'b', 'linewidth',1.5);
semilogy(Pt, ber_th1, '*r','linewidth',1.5);
semilogy(Pt, ber_th2, '*b','linewidth',1.5);
xlabel('Transmit power (P in dBm)');
ylabel('BER');
legend('Sim. User 1/Far user','Sim. User 2/Near user','Theo. User 1/Far user','Theo. User 2/Near user');
```