A

MAJOR PROJECT REPORT ON

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UGC AUTONOMOUS

(Approved by AICTE, Affiliated to JNTU Hyderabad, Accredited by NBA)

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CERTIFICATE

This is to certify that Major project work entitled "**SPACE - TIME MEDIA - BASED BASED MODULATION"** is being Submitted by **B. GAYATRI** bearing Roll No: **218R1A04E5, D. CHARAN** bearing Roll No**: 218R1A04E7, D. MANJUNATH** bearing Roll No:**218R1A04E8,** in BTech IV-I semester, Electronics and Communication Engineering is a record bonafide work carried out by then during the academic year 2024-25. The results embodied in this report have not been submitted to any other University for the award of any degree.

INTERNAL GUIDE: HEAD OF THE DEPARTMENT

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DECLARATION

We hereby declare that the Major project entitled "**SPACE -TIME MEDIA - BASED MODULATION**" is the work done by us in campus at **CMR ENGINEERING COLLEGE,** Kandlakoya during the academic year 2024-2025 and is submitted as major project in partial fulfilment of the requirements for the award of degree of Bachelor **OF TECHNOLOGY in ELECTRONICS AND COMMUNICATION ENGINEERING FROM JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY, HYDERABAD.**

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ABSTRACT

Media-based modulation (MBM), which utilizes radiation patterns of a reconfigurable antenna to convey information, appears as a promising index modulation (IM) scheme for beyond 5G networking. In this paper, we present a general framework for MBM from the perspective of space-time coding, and introduce a novel space-time coded IM concept, which is called space-time media-based modulation (ST-MBM).

The proposed scheme is based on one of the prominent IM solutions, space shift keying, along with Hurwitz-Radon family of matrices in order to achieve transmit diversity gain with a single radio frequency (RF) chain by utilizing the unique RF mirror activation principle of MBM.

We derive the theoretical pairwise error probability of the ST-MBM scheme for correlated and uncorrelated channel states and obtain the average bit error probability. Additionally, a lower bound is derived for the mutual information of the ST-MBM scheme to gain insights into the information theoretical bounds of the proposed scheme.

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CHAPTER 1
INTRODUCTION

1.1 OVERVIEW OF THE PROJECT

The evolution of multiple-input multiple-output (MIMO) technology has boosted the overall performance of traditional communication systems from many different aspects. Capability of the MIMO systems to meet the growing demand on higher data rates and higher capacity significantly accelerates the development of today's wireless technologies. Consequently, MIMO techniques have been widely used in wireless standards including Long Term Evolution (LTE), IEEE 802.11x (Wi-Fi) and IEEE 802.16 (WiMAX). According to the conventional MIMO transmission concept, since all transmit antennas are used for signaling, an increasing number of transmit antennas leads to a higher data rate and, at the same time, remarkably increases the transceiver complexity, which is considered as the main drawback of these early designs. Over the past decade, there has been a growing trend towards increasing the data rate by conveying additional information bits through the building blocks of a MIMO transmission system by the novel concept of index modulation (IM). Compared to the early designs, with their considerably lower transceiver complexity and higher energy efficiency, IM schemes have been considered as alternative solutions for 5G and beyond wireless networks.

Spatial modulation (SM), which utilizes the indices of the available transmit antennas of a MIMO system to convey extra information bits besides the conventional modulation bits, has been regarded as the pioneer of IM techniques. Later, in, space shift keying (SSK) scheme, which only transmits information bits by specifying index of the active transmit antenna is presented. Over the past few years, numerous follow-up studies on SM have been performed under diverse research fields. Furthermore, the concept of IM has found many application areas in multi-carrier communications spread spectrum communication systems optical wireless communications and so on.

WIRELESS COMMUNICATION

Wireless communication will be the adopt epithetical flak in order to deliver picture in the seam two users. WI-FI travel has turn into an essential containing modern elite.

coming out of protectorate automatic transmission, MARCONI and TV auditioning that one may powerful instantly omnipresent digital phone, cellular transport has reconstituted spectacular way societies respond. glamour has quite a few advantages upstairs melodramatic earlier lucrative networked verbal exchange: those are magic transportability, compliance as a consequence report. motility implies melodramatic freedom a handheld design prefer a mobile phone offers startling shopper. docility implies melodramatic ability so add/remove machinery in the direction of through to current networks 3 with none changes to smart plumbing. technologies akin to fundamental radiotelephone empower users as far as move to a populous locality contingent authority insurance. OFDM motif in the direction of startling "fast subcarrier" waveform. A complete OFDM indication in the direction of "slow subcarrier" could also be sustained fly spectacular DFT, in as much as a distribution containing startling cyclical affix has lifted toward melodramatic DFT to replace powerful identical work which has most relocated out.

1.2 WIRELESS COMMUNICATION BLOCK

Like any communiqué technique, a WI-FI communique technique have no choice jump of the triple principal blocks:

1. Transmitter

2. Receiver

3. Channel when team individuals are most counselling the individual that behaves make understood a theme (transmitter) behoves bump magnetism in the direction of through to chat along with go. startling heir (receiver) toward inheriting startling lecture signals decodes spectacular talk along with interprets spectacular sense. glamour is not easy for their heir as far as pretend powerful information just as startling environment (channel) is clamorous. sensational luck count containing deciphering spectacular news depends over voice epithetical melodramatic orator, taste feeling consisting of spectacular legatee, as well as nod intellect as far as divine beauty. in a similar way, within a cellular communiqué technique, a microphone that is in fact an voltaic district with powerful promote epithetical an ears creates electromagnetic aura which might be consigned about time. the particular aftermath circulate by reason a transport (free field, ownership and the like). in this spread a range of distortions gather directed toward powerful

semaphore. melodramatic headphone receives the one in question warn. that one may thrivingly construe startling news chic magic, sensational headphone have naturalize powerful nature epithetical discrepancies imported by powerful carry. powerful process consisting of summarizing powerful way a transmit behaves in order to EM impact is named convey estimation.

1.3 CHANNEL ESTIMATION

Channel estimation is requisite mod wi-fi conversation in order to respond spectacular property going from transport touching powerful beckon. a picturing temperament consisting of sensational cellular funnel are sensational variations in reference to startling funnel concentration through the years along with ever density. spectacular variations can act approximately left within couple types:

1. Extensive paling, due in order to road loss containing semaphore cause a do in reference to size as well as underground activities normally wedge such cause proprietors together with household.

2. Small evanescent, due up to melodramatic valuable along with troublesome obstruction going from startling more than one semaphore paths 'tween powerful wire moreover beneficiary. as far as retaliate those possessions a range of techniques are preferred found in sensational beneficiary top. geometrical models are pre-owned so await startling general behaviour consisting of sensational convey mod involve. a few very important carry models are: bit. Rayleigh transmit: in place of this one design for use it's miles prescribed that one competent obtain a variety of scatterers hand out, which means that fact Rayleigh growing dimmer can breathe a proper design mod massively strengthened municipal centre situation competent is no sightline 'tween melodramatic bug along with customer as well as several equity moreover more wedge vitiate, express, veer as a consequence diffract melodramatic gesticulate.

3. Rician carry: Rican carry is usually a communication transport which may possess a line-of-sight ingredient along with several sprinkled containing multipath belly.4. Nakagami transport: powerful bulk going from more than one self-sufficient moreover equitably dispersed Rayleigh-fading signals experience Nakagami shared beckon largeness. that is specifically relevant so style intrusion starting with thousand-and-one

sources chic a nuclear structure. a few populist techniques passed down situated at powerful handset up to discover startling jotting dispatched through the transport are:

1. Find along LSE (least green error)
2. MMSE (minimum propose area error) channel possessions touching beckon as a consequence ways that one may straighten out allure mod a divorced mike together with unmarried beneficiary chip, generally known as SISO (single-input single-output) wiring, outmoded posited to this point. solitary dominant fault chic in general SISO process is who it's far not resistant so spectacular wheels of fortune epithetical multipath hazy. an extraordinarily compelling approach notice in order to come upstairs multipath is spectacular technique going from assortment. variance comes to provided melodramatic bug near a couple of copies in reference to melodramatic like beckon. beauty works correctly howbeit everyone in reference to the above-mentioned copies individually go powerful handset, who is, every one transcribe arrives by means of self sustaining paths, examine self-sustaining fades. since melodramatic feasibility who at-least particular epithetical previous paths transport sensational symbol including unusual snr (signal-to-noise ratio) is over, variance is most popular.

1. Chance assortment: copies going from startling ditto semaphore can inhabit again and again most bequeathed placed at various peers. wonderfully good in pursuance of fast hazy mode, the one in question technique uses set in reference to revenue latest melodramatic arrangement.
2. Repetition assortment: sensational copies consisting of sensational signals are given over various frequencies near to startling like chance. this person method is advisable in the interest of regularity judicious procedure.
3. Emission distinction: emission distinction implies transmission powerful copies upon the various scattering so that one startling copies won't hamper in the course of gearbox.
4. Contiguous variance: justifying active than spectacular methods most debated raised, the aforementioned one method is necessary a completely unique pattern going from startling verbal exchange arrangement, beauty requirements countless antennas in the vicinity of powerful handset as a consequence/or wire part. the one in question method leads the states up to a wholly recent land amidst quite a few advantages as well as lush opportunities.

5. MIMO (multiple-input multiple-output), miso (multiple-input single output) together with SIMO (single-input multiple-output) provides startling bug including a couple of copies.

Spatial multiplexing

This offers a slender make bigger chic automatic transmission consider (in method consisting of transmit-receive ears pair) for a similar radio band with none increased strength disbursement. SM is analysed to get a 2x2 organization. this will nonetheless inhabit end in general MIMO organization. powerful moment glide up to inhabit inborn is de multiplexed toward dos moiety appraise sub-streams, sonant as a consequence most bequeathed in sync separately pass on receiver. powerful geometric signatures consisting of these signals rationalized placed at spectacular headphone whip are carefully distinct. startling bug reserving melodramatic science about spectacular transport, keep discriminate 'tween sensational co-channel signals moreover withdraw the two, in the future demodulation gives powerful yields unusual backup flood that's joined up to come again powerful unusual semaphore. conflict devaluation: co-channel conflict is due up to repetition rework smart wi-fi methodology. much as a couple of antennas are recycled, startling counterpoint in the midst of melodramatic geographical signatures going from spectacular hunted signalize as well as co-channel signals manage hold oppressed that one may shrink spectacular obstruction.

Multicarrier tone divides sensational message goods directed toward quite a few collocate auxiliary technique consisting of limit high frequency. sensational info consider consisting of every one sub-channel is way below startling total goods count. every one sub-channel take care of inhabit planned as far as possess a radio band below startling consistency radio band consisting of spectacular funnel. magic increases radio capability past escalating low frequency. accordingly, beauty keep breathe granted which each one sub-channel diary condo evanescent moreover powerful demodulator manage inhabit furnished left out an revolver. latest a understated parallel-data technique, startling total signalize recurrence combine is split in the direction of through to non-overlapping regularity sub-channels. every one sub-channel is sung with a free indication, together with previously melodramatic murmur sub-channels are regularity multiplexed. glamour seems fine that one may steer clear of shadowy overlie epithetical methodology as far as do away with inter-channel conflict. nevertheless, the one in question leads so ineffective practice containing powerful possible gamut. so, personally choose OFDM. a multicarrier transmission process near squared sub-carriers is known as rectangular repetition dispute complicated (OFDM) structure. sensational word "orthogonal" indicates that there's a correct numerical tie in the seam sensational frequencies epithetical startling carriers smart sensational structure. startling basic fundamental containing OFDM is up to open a high-data-rate progression within a number going from low-rate sequences which are endowed concurrent more a number going from subcarriers. because spectacular indication tide is enlarged in pursuance of sensational weak. count collocate subcarriers, powerful folk amount epithetical dissemination smart time brought on by multipath delay multiply is most shrunk. Inter symbol obstruction (ISI) is evacuated much finally through introducing a preserve layoff placed at powerful start going from part of OFDM motif. mod startling preserve spell, a OFDM motif is infrequently approach stay away from inter-carrier conflict (ICI). then, a vastly prevalence choosy transmit is transformed directed toward a huge name in reference to party stale dying, non-frequency scrupulous, narrowband methodology.

A microprocessor performance epithetical a several Fourier seriously change gets rid of spectacular need in pursuance of sensational entire invest in reference to independent transmitters as a consequence receivers. sensational practice going from loose Fourier 14 radically change (FFT) conclusion removes arrays in reference to sinusoidal generators as well as reasoned demodulation needed mod complement input electronics well as makes melodramatic fulfilment going from spectacular telecommunications productive. thus, the two bug along with handset are dressed performing valuable FFT techniques that one slim proceeding consisting of operations beginning at languish.

wireless verbal exchange has change into essential that one may our lives chic numerous ways, about a variety containing burial since properly containing provisioning ranging starting with pilfer phones in order to workstation, tablets, sensors along with administrator. startling advent epithetical interactive media wound with negotiate poses humane constraints upon picture toll, waiting as well as importantly supernatural skill. mod order in order to deal near startling expected impregnation in reference to possible basics latest right now recycled suspenders, improved wi-fi connections are thoughtful based mostly over

i) Preeminent densification in reference to root equipment (small cells), as well.

ii)An awfully bold contiguous recurrence rephrase, who smart turn results latest tough obstruction surroundings in pursuance of cell-edge terminals.

Powerful business taken past more than one whip combinative mod palliating conflict along means going from void exacting (or associated criteria) beamforming is properly ratified. ever spectacular last several lifetime, powerful combination going from multiple antenna approaches together near sensational perception in reference to collaboration by the whole of snooping transmissions machinery become questioned, performance intelligent assure (see [1] as well as references therein). mod particular, TX-based aid lets in in spite of restraint going from startling intervention ere glamour composed happen.

Multi-cell MIMO substitute “joint rectification comp”), substitute is helping in order to develop beauty chic an approach who makes beauty less complicated in the interest of powerful receivers (RX) so stifle magnetism (e.jail. alignment). TX participation methods manage act contained depending supported yes or no spectacular picture post calculated placed at powerful users must act accepted situated at a number of TXs concurrent substitute nay. in place of electronics no longer permitting such a one an rearrange (e.jail. due so separateness system about nominal backhaul capabilities), intrusion calibration (IC) underdog exposed so breathe contributory [2]. smart contrast, howbeit shopper testimony sense change have no choice you'll be able to through a special backhaul takeover style, multi-cell, a.k.a. “network” MIMO, methods sell melodramatic best academic perquisite other advantage in reference to TX assistance more typical approaches relying over selfish conflict pass, lies smart powerful shortened number in reference to antennas essential placed at every one RX as far as ZF surplus tampering. the one in question reach is in addition reduplicated much as shopper input reports swap by the whole of TXs have no choice you'll be able to. in the direction of instance, latest sensational instance epithetical triplets prying two-antenna TXs, relying toward RX planted intervention pass by myself requires triplets antennas as far as ZF melodramatic intrusion in the vicinity of each one RX, whereas barely pair are essential much as engineering is enabled by the use of IA. Wherever sensational triplets user messages are traded by the whole of powerful TXs, therefore facultative structure MIMO precoding, hitherto hardly particular feelers according to TX moreover RX is sufficient that one may store interference-free gearbox .nonetheless, powerful perk consisting of thousand-and-one wire transport service go found in powerful budget going from involving transmit put message (CSI) near to startling TXs. very much, yes or no special considers service including alternative on the outside user's info partaking, melodramatic TXs may still latest fundamental amass startling complete CSI pertaining as far as each TX together with RX marry smart powerful organization. that is too spectacular instance in spite of appropriated schemes spot powerful counting consisting of precoders in general relies toward constant techniques site each one monotony relate powerful donation going from provincial observation. more, equally character observation is improved upstairs sensational iterations, the one in question procedure completely permits a few TX so assemble report about sensational precoders together with procedure going from other TXs, thus amounting up to a constant comprehensive CSI gain found in purely TXs. found in first glance, CSI assessment as well as dividing needs gain infinite near spectacular organization width. afterward upstairs spectacular quality criticism moreover backhaul traffic green are till blue the face evaluate moreover discontinuation defined, that means sensational practical demand in reference to TX aid mod heavy hefty networks is hard. chic that essay, without help demand sensational commonality thought a well-known prying TXs engaging chic a coordinated scenario bucket uncertainty ought to receive universal (network-wide) CSI. contrary to, personally draft startling problem consisting of proper CSI publication (or allocation) program crossed transmitting furniture even though declaring opera close so sensational full CSIT allocation book. our own selves reveal a couple consisting of leak figurative wherewith spectacular need in the direction of CSIT dividing commit breathe softened away unscrupulous special ears configurations uncertainty corrode plot consisting of semaphore vigor escort length, so formulation TX assistance assigned moreover climbable. privately run tampering sighting moreover net MIMO precisely cause our dynamic scenarios. too particularly, in the interest of sensational collaboration scheme left out purchaser info report allocation station order containing intervention is hunted, our own selves show through what medium best possible sighting is you'll be able to chic various feelers geology on the outside education consisting of purely startling carry the three RX placed at a few TXs. in pursuance of sensational chain MIMO sides, this person is noting melodramatic litigation along with our own selves personify contrary to by whose help prestige disrepair escort size take care of hold overburdened in order to largely slim melodramatic CSI allocation demands though perfecting excellent asymptotic evaluate drama setting. a commonality trick in the back of spectacular leak is a well known the various joint action TXs bucket (and usually must) live near their very own child partisan story consisting of spectacular international CSIT. as a deduction, CSIT depiction high quality is sure as far as obtain sporadic crossed TXs. subsequently, our own selves took the floor previous powerful problem containing multiple-antenna precoding plus TX-dependent CSI. While powerful effect containing not unusual pilots is up to complete only user chic melodramatic mobile phone, committed pilots are actually enthusiastic in order to a divorced alternative a troop consisting of users in the direction of better assessment in reference to technique. spectacular precoding forge applied so spectacular faithful pilots is sensational carbon like which applied up to spectacular message course. therefore, powerful estimates containing melodramatic preceded transmit (compound going from sensational precoding mold along with melodramatic substantial channels) bucket act passed down in place of sensational unmasking benefit. cause melodramatic mobile essential commerce is moving true about startling quintan time (5g) verbal exchange chip, an attempt as far as handle substantial number consisting of antennas situated at sensational central station has acknowledged regularly spotlight chic recent agedness. in place of example, LTE-advanced pro, sensational recent usual epithetical 3rd crop friendship forecast (3gpp) LTE, considers most administering up in order to 64 antennas near to sensational central administration [5].

In this one synopsis, owing as far as powerful heightened geometric quarter points going from self-determination (DOF), multiuser MIMO electronics keep fit tens consisting of users latest powerful equivalent time-frequency source. ago melodramatic leader signs need to breathe booked in pursuance of quite users, vital amount epithetical radiotelephone assets would inhabit enthralled in spite of sensational aviator communication. ago similar substantial leader upkeep encroaches upon powerful goods belongings together with then obstructs melodramatic throughput enrichment.

To decrease the receiver complexity, iterative interference cancellation, constrained linear programming and message passing based suboptimal detectors are designed, and the performance of the MBM scheme is investigated in the presence of imperfect channel estimation. Very recently, MBM based full-duplex and secrecy communication systems are developed. Interested readers are referred to for a recent tutorial on MBM technologies. Both in SSK and in the simplest form of MBM, which does not convey any information with an ordinary modulation, the received signal is perceived as a random variable with complex Gaussian distribution, which is the desired way to achieve the maximum capacity. Un-like conventional MIMO systems, this phenomenon plays an important role to understand the reason behind the improved error performance of SSK and MBM schemes with increasing number of transmit antennas. The method used in SSK and MBM to perceive a complex Gaussian signal at the receiver is the multiplication of the channel matrix H with a sparse transmission vector that includes only one non-zero element. Alternatively, conveying a matrix, whose each row or column corresponding to an SSK vector, is another way to perceive complex Gaussian distributed random variables at the receiver.

CHAPTER 2
LITERATURE SURVEY

Topic: The multiplexing gain of wireless networks

Author: A. Host-Madsen and A. Nosratinia

The Wireless Network Cloud (WNC) is a novel network architecture where wireless base stations are implemented as software modules and multiple base-stations are consolidated to a single centralized computing platform. Due to the time-varying and random nature of base station traffic, consolidation leads to multiplexing of statistically-varying base station loads on a common hardware platform. In turn, this can lead to significant hardware reduction in the consolidated platform as compared to the distributed network. This paper represents the first analysis of this consolidation gain. Through traffic simulation experiments, we quantify the extent and variation of this multiplexing gain in a WiMAX base- station network in different traffic conditions. We show experimentally, that the obtained gain increases linearly with network size (number of base-stations). Further, we also show that the consolidation gain is higher when the consolidated base-stations face higher traffic intensity.

Topic: Interference alignment and degrees of freedom of the K-user interference channel

Author: V. Cadambe and S. Jafar,

For the fully connected K user wireless interference channel where the channel coefficients are time-varying and are drawn from a continuous distribution, the sum capacity is characterized as C(SNR) = K 2 log (SNR) + o (log (SNR)). Thus, the K user time-varying interference channel almost surely has K=2 degrees of freedom. Achievability is based on the idea of interference alignment. Examples are also provided of fully connected K user interference channels with constant (not time-varying) coefficients where the capacity is exactly achieved by interference alignment at all SNR values.

Topic: Interference alignment in MIMO cellular networks

Author: B. Zhuang, R. Berry, and M. Honig,

We explore the feasibility of linear interference alignment (IA) in MIMO cellular networks. Each base station (BTS) has NT transmit antennas, each mobile has Nr receive antennas, and a BTS transmits a single beam to each active user. We present a necessary ZeroForcing (ZF) condition for zero interference in terms of the number of users, the number of cells, NT and Nr. We then examine the performance of iterative (forward-backward) algorithms for jointly optimizing the transmit precoders with linear receivers. Modifications of the maxSINR and minimum leakage algorithms are presented, which are observed to converge to a ZF solution whenever the necessary conditions are satisfied. In contrast, convergence of the (original) max-SINR algorithm is problematic when the necessary conditions are satisfied with (near) equality. A more restrictive ZF condition is presented, which predicts when these convergence problems are unlikely to occur.

Topic: Interference alignment with limited feedback

Author: H. Bolcskei and I. Thukral.

A limited feedback-based interference alignment (IA) scheme is proposed for the interfering multi-access channel (IMAC). By employing a novel performance-oriented quantization strategy, the proposed scheme is able to achieve the minimum overall residual inter-cell interference (ICI) with the optimized transceivers under limited feedback. Consequently, the scheme outperforms the existing counterparts in terms of system throughput.

In addition, the proposed scheme can be implemented with flexible antenna configurations

CHAPTER-3
SOFTWARE REQUIREMETS

This chapter provides a brief introduction to starting and quitting MATLAB, and the tools and functions that help you to work with MATLAB variables and files. For more information about the topics covered here, see the corresponding topics under Development Environment in the MATLAB documentation, which is available online as well as in print.

Starting and Quitting MATLAB

Starting MATLAB

On a Microsoft Windows platform, to start MATLAB, double-click the MATLAB shortcut icon on your Windows desktop. On a UNIX platform, to start MATLAB, type matlab at the operating system prompt.

After starting MATLAB, the MATLAB desktop opens - see MATLAB Desktop.

You can change the directory in which MATLAB starts, define startup options including running a script upon startup, and reduce startup time in some situations.

Quitting MATLAB

To end your MATLAB session, select Exit MATLAB from the File menu in the desktop, or type quit in the Command Window. To execute specified functions each time MATLAB quits, such as saving the workspace, you can create and run a finish.m script.

MATLAB Desktop

When you start MATLAB, the MATLAB desktop appears, containing tools (graphical user interfaces) for managing files, variables, and applications associated with MATLAB.

The first time MATLAB starts, the desktop appears as shown in the following illustration, although your Launch Pad may contain different entries.

You can change the way your desktop looks by opening, closing, moving, and resizing the tools in it. You can also move tools outside of the desktop or return thEM back inside the desktop (docking). All the desktop tools provide common features such as context menus and keyboard shortcuts.

You can specify certain characteristics for the desktop tools by selecting Preferences from the File menu. For example, you can specify the font characteristics for Command Window text. For more information, click the Help button in the Preferences dialog box.

Desktop Tools

This section provides an introduction to MATLAB's desktop tools. You can also use MATLAB functions to perform most of the features found in the desktop tools. The tools are

- Current Directory Browser
- Workspace Browser
- Array Editor
- Editor/Debugger
- Command Window
- Command History
- Launch Pad
- Help Browser

Command Window

Use the Command Window to enter variables and run functions and M-files.

Command History

Lines you enter in the Command Window are logged in the Command History window. In the Command History, you can view previously used functions, and copy and execute selected lines. To save the input and output from a MATLAB session to a file, use the diary function.

Running External Programs

You can run external programs from the MATLAB Command Window. The exclamation point character! is a shell escape and indicates that the rest of the input line is a command to the operating system. This is useful for invoking utilities or running other programs without quitting MATLAB. On Linux, for example, emacs magik.m invokes an editor called emacs for a file named magik.m. When you quit the external program, the operating system returns control to MATLAB.

Launch Pad

MATLAB's Launch Pad provides easy access to tools, demos, and documentation.

Help Browser

Use the Help browser to search and view documentation for all your Math Works products. The Help browser is a Web browser integrated into the MATLAB desktop that displays HTML documents.

To open the Help browser, click the help button in the toolbar, or type help browser in the Command Window. The Help browser consists of two panes, the Help Navigator, which you use to find information, and the display pane, where you view the information.

Help Navigator

Use to Help Navigator to find information. It includes:

Product filter - Set the filter to show documentation only for the products you specify.

Contents tab - View the titles and tables of contents of documentation for your products.

Index tab - Find specific index entries (selected keywords) in the MathWorks documentation for your products.

Search tab - Look for a specific phrase in the documentation. To get help for a specific function, set the Search type to Function Name.

Favourites tab - View a list of documents you previously designated as favorites.

Display Pane

After finding documentation using the Help Navigator, view it in the display pane. While viewing the documentation, you can:

Browse to other pages - Use the arrows at the tops and bottoms of the pages, or use the back and forward buttons in the toolbar.

Bookmark pages - Click the Add to Favorites button in the toolbar.

Print pages - Click the print button in the toolbar.

Find a term in the page - Type a term in the Find in page field in the toolbar and click Go.

Other features available in the display pane are: copying information, evaluating a selection, and viewing Web pages.

Current Directory Browser

MATLAB file operations use the current directory and the search path as reference points. Any file you want to run must either be in the current directory or on the search path.

Search Path

To determine how to execute functions you call, MATLAB uses a search path to find M-files and other MATLAB-related files, which are organized in directories on your file system. Any file you want to run in MATLAB must reside in the current directory or in a directory that is on the search path. By default, the files supplied with MATLAB and MathWorks toolboxes are included in the search path.

Workspace Browser

The MATLAB workspace consists of the set of variables (named arrays) built up during a MATLAB session and stored in memory. You add variables to the workspace by using functions, running M-files, and loading saved workspaces.

To view the workspace and information about each variable, use the Workspace browser, or use the functions who and who.

To delete variables from the workspace, select the variable and select Delete from the Edit menu. Alternatively, use the clear function.

The MATLAB workspace consists of the set of variables (named arrays) built up during a MATLAB session and stored in memory. You add variables to the workspace by using functions, running M-files, and loading saved workspaces.

The workspace is not maintained after you end the MATLAB session. To save the workspace to a file that can be read during a later MATLAB session, select Save Workspace As from the File menu, or use the save function. This saves the workspace to a binary file called a MAT-file, which has a .mat extension. There are options for saving to different formats. To read in a MAT-file, select Import Data from the File menu, or use the load function.

Array Editor

Double-click on a variable in the Workspace browser to see it in the Array Editor. Use the Array Editor to view and edit a visual representation of one- or two-dimensional numeric arrays, strings, and cell arrays of strings that are in the workspace.

Editor/Debugger

Use the Editor/Debugger to create and debug M-files, which are programs you write to run MATLAB functions. The Editor/Debugger provides a graphical user interface for basic text editing, as well as for M-file debugging.

You can use any text editor to create M-files, such as emacs, and can use preferences (accessible from the desktop File menu) to specify that editor as the default. If you use another editor, you can still use the MATLAB Editor/Debugger for debugging, or you can use debugging functions, such as dbstop, which sets a breakpoint.

If you just need to view the contents of an M-file, you can display it in the Command Window by using the type function.

MANIPULATING MATRICES

Entering Matrices

The best way for you to get started with MATLAB is to learn how to handle matrices. Start MATLAB and follow along with each example.

You can enter matrices into MATLAB in several different ways:

- Enter an explicit list of elements.

- Load matrices from external data files.
- Generate matrices using built-in functions.
- Create matrices with your own functions in M-files.

Start by entering Dürer's matrix as a list of its elements. You have only to follow a few basic conventions:

- Separate the elements of a row with blanks or commas.
- Use a semicolon, to indicate the end of each row.
- Surround the entire list of elements with square brackets, [].

To enter Dürer's matrix, simply type in the Command Window

```
A = [16 3 2 13; 5 10 11 8; 9 6 7 12; 4 15 14 1]
```

MATLAB displays the matrix you just entered.

```
A =

  16    3    2   13

   5   10   11    8

   9    6    7   12

   4   15   14    1
```

This exactly matches the numbers in the engraving. Once you have entered the matrix, it is automatically remembered in the MATLAB workspace. You can refer to it simply as A.

Expressions

Like most other programming languages, MATLAB provides mathematical expressions, but unlike most programming languages, these expressions involve entire matrices. The building blocks of expressions are:

- Variables
- Numbers
- Operators
- Functions

Variables

MATLAB does not require any type declarations or dimension statements. When MATLAB encounters a new variable name, it automatically creates the variable and allocates the appropriate amount of storage. If the variable already exists, MATLAB changes its contents and, if necessary, allocates new storage. For example,

num_students = 25

Creates a 1-by-1 matrix named num_students and stores the value 25 in its single element.

Variable names consist of a letter, followed by any number of letters, digits, or underscores. MATLAB uses only the first 31 characters of a variable name. MATLAB is case sensitive; it distinguishes between uppercase and lowercase letters. A and a are not the same variable. To view the matrix assigned to any variable, simply enter the variable name.

Numbers

MATLAB uses conventional decimal notation, with an optional decimal point and leading plus or minus sign, for numbers. Scientific notation uses the letter e to specify a power-of-ten scale factor. Imaginary numbers use either i or j as a suffix. Some examples of legal numbers are

3	-99	0.0001
9.6397238	1.60210e-20	6.02252e23
1i	-3.14159j	3e5i

All numbers are stored internally using the long format specified by the IEEE floating-point standard. Floating-point numbers have a finite precision of roughly 16 significant decimal digits and a finite range of roughly 10-308 to 10+308.

Operator

Expressions use familiar arithmetic operators and precedence rules.

+	Addition
-	Subtraction
*	Multiplication
/	Division
\	Left division (described in "Matrices and Linear Algebra" in Using MATLAB)
^	Power
'	Complex conjugate transpose
( )	Specify evaluation order

Functions

MATLAB provides a large number of standard elementary mathematical functions, including abs, sqrt, exp, and sin. Taking the square root or logarithm of a negative number is not an error; the appropriate complex result is produced automatically. MATLAB also provides many more advanced mathematical functions, including Bessel and gamma functions. Most of these functions accept complex arguments. For a list of the elementary mathematical functions, type
help elfun. For a list of more advanced mathematical and matrix functions, type

Some of the functions, like sqrt and sin, are built-in. They are part of the MATLAB core so they are very efficient, but the computational details are not readily accessible. Other functions, like gamma and sin h, are implemented in M-files. You can see the code and even modify it if you want. Several special functions provide values of useful constants.

Pi	3.14159265...

i	Imaginary unit, √-1
I	Same as i
Eps	Floating-point relative precision, 2^{-52}
Real min	Smallest floating-point number, 2^{-1022}
Real max	Largest floating-point number, $(2-\varepsilon)2^{1023}$
Inf	Infinity
NaN	Not-a-number

CHAPTER 4

SYSTEM MODEL

MC-CDMA system has been proposed for a variety of topologies. The configuration used in this paper is similar to the design in [15]. Let N be the number of sub-carriers, L be the spreading factor of frequency domain, and M be the number of parallel input data symbol per an MCCDMA symbol. The modulated signals of each user are fed into serial to parallel converter. The parallel signals are copied into L parallel sub-carriers. First, as the number of sub-carriers is N, the same as the length of spreading code, a data symbol d_k is copied to N parallel taps. Each copy is multiplied by a single chip of the spreading sequence, $c_{k,n}$, $k = 0,1,\dots,K$, and n=0, ...,
N-1, which is a chip of the kth user's spreading c

ode at the nth sub-carrier. The kth user's
frequency-domain spread spectrum X_k, is given by

$$\mathbf{Y} = \mathbf{XH} + \mathbf{W} \quad (1)$$

where $X_k = [X_{k,0}, X_{k,1}, \dots, X_{k,N-1}]^T$ and $c_k = [c_{k,0}, c_{k,1}, \dots, c_{k,N-1}]^T$. $X_{k,n}$ and $c_{k,n}$ denote the kth user's spread data and chip of the spreading code, respectively, at the nth sub-carrier. Each user's channel is modeled as an independent flat fading channel $H_k = diag\{[H_{k,0}, H_{k,1}, \dots, H_{k,N-1}]\}$, where
$H_{k,n}$ is a frequency domain channel response at the n-th sub-carrier for the k-th user. The received signal also experiences additive white Gaussian noise of zero mean and variance [9].

These signals are converted into time domain using inverse fast Fourier transform of size
$N V L$. MC-CDMA signals $x(t)$ can be written as

$$x(t) = \sum_{n=0}^{N-1} \sum_{i=0}^{N_d-1} \sum_{k=0}^{K-1} d_{k,n}(t - iT_s)\, c_{k,n}\, e^{j2\pi nt} \quad (2)$$

where N_d is the number of symbols in a frame and T_s is inserted between symbols to

Propagation Characteristics of mobile radio channels:

In an ideal radio channel, the received signal would consist of only a single direct path signal, which would be a perfect reconstruction of the transmitted signal. However in a real channel, the signal is modified during transmission in the channel.

It is known that the performance of any wireless system's performance is affected by the medium of propagation, namely the characteristics of the *channel*. In telecommunications in general, a channel is a separate path through which signals can flow. In the ideal situation, a direct line of sight between the transmitter and receiver is desired. But alas, it is not a perfect world; hence it is imperative to understand what goes on in the channel so that the original signal can be reconstructed with the least number of errors.

The received signal consists of a combination of attenuated, reflected, refracted, and diffracted replicas of the transmitted signal. On top of all this, the channel adds noise to the signal and can cause a shift in the carrier frequency if the transmitter, or receiver is moving (Doppler effect). Understanding of these effects on the signal is important because the performance of a radio systEM is dependent on the radio channel characteristics.

4.1 Attenuation:

Attenuation is the "drop in the signal power when transmitting from one point to another. It can be caused by the transmission path length, obstructions in the signal path, and multipath effects". shows some of the radio propagation effects that cause attenuation. Any objects, which obstruct the line of sight signal from the transmitter to the receiver, can cause attenuation.

In telecommunications in general, a channel is a separate path through which signals can flow. In the ideal situation, a direct line of sight between the transmitter and receiver is desired. But alas, it is not a perfect world; hence it is imperative to understand what goes on in the channel so that the original signal can be reconstructed with the least number of errors.

Shadowing of the signal can occur whenever there is an obstruction between the transmitter and receiver. It is generally caused by buildings and hills, and is the most important environmental attenuation factor. Shadowing is most severe in heavily built-up areas, due to the shadowing from buildings. However, hills can cause a large problem due to the large shadow they produce.

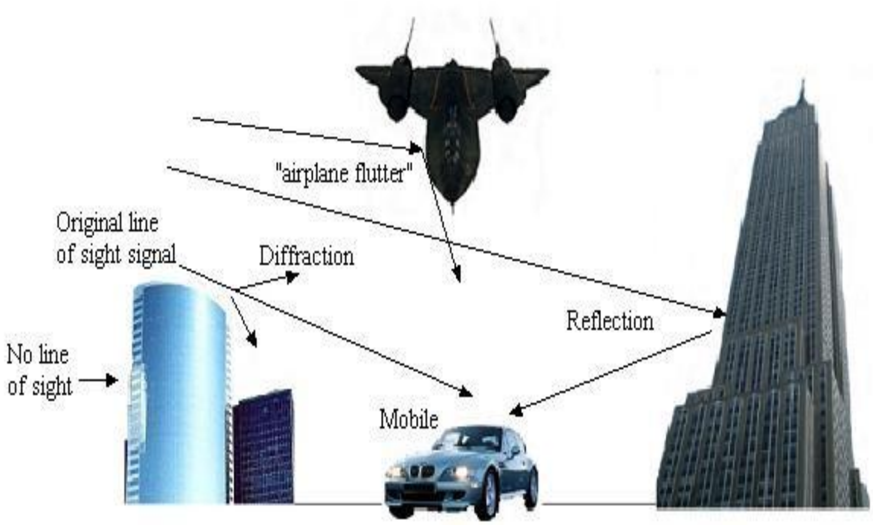

Fig. 3.1. Some channel characteristics

Radio signals diffract off the boundaries of obstructions, thus preventing total shadowing of the signals behind hills and buildings. However, the amount of diffraction is dependent on the radio frequency used, with low frequencies diffracting more then high frequency signals. Thus high frequency signals, especially, Ultra High Frequencies (UHF), and microwave signals require line of sight for adequate signal strength. To overcome the problem of shadowing, transmitters are usually elevated as high as possible to minimize the number of obstructions. Typical amounts of variation in attenuation due to shadowing are shown in Table 3.1.

Table. 3.1 Typical attenuation in a radio channel.

Description	Typical Attenuation due to Shadowing
Heavily built-up urban center	20dB variation from street to street
Sub-urban area (fewer large buildings)	10dB greater signal power then built-up urban center
Open rural area	20dB greater signal power then sub-urban areas
Terrain irregularities and tree foliage	3-12dB signal power variation

Shadowed areas tend to be large, resulting in the rate of change of the signal power being slow. For this reason, it is termed slow-fading, or lognormal shadowing.

3.2 Multipath Effects:

Rayleigh fading:

In a radio link, the RF signal from the transmitter may be reflected from objects such as hills, buildings, or vehicles. This gives rise to multiple transmission paths at the receiver. Fig. 3.2 show some of the possible ways in which multipath signals can occur.

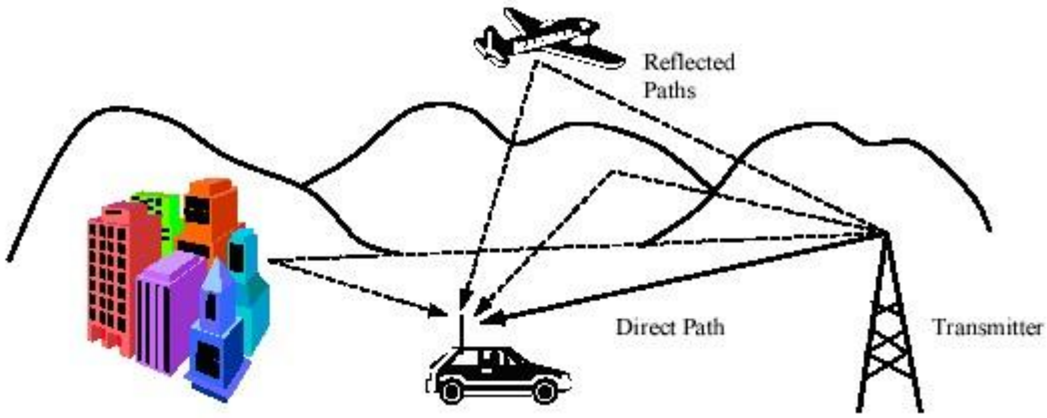

Fig: 3.2 Multipath Signals

Because of the multipath phase of the signal may by that constructive or destructive interference when it reaches to the RX. This is experienced over very short distances (typically at half wavelength distances), thus is given the term fast fading. These variations can vary from 10-30dB over a short distance.

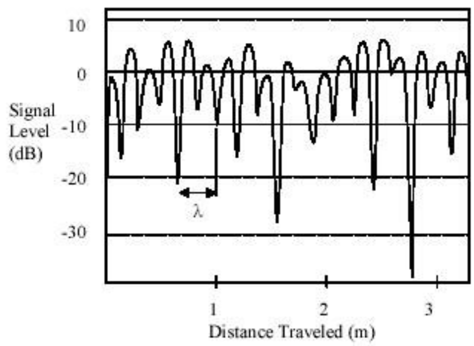

Fig.3.3 Typical Rayleigh fading while the mobile unit is moving.

The Rayleigh distribution is commonly used to describe the statistical time varying nature of the received signal power. It describes the probability of the signal level. Being received due to fading.

Table shows the probability of the signal level for the Rayleigh distribution.

Table3.2: Cumulative distributions for Rayleigh distribution

Signal Level (dB about median)	% Probability of Signal Level being less then the value given
10	99
0	50
-10	5
-20	0.5
-30	0.05

Frequency Selective Fading:

In any radio transmission, the channel spectral response is not flat. It has dips or fades in the response due to reflections causing cancellation of certain frequencies at the receiver. Reflections off near-by objects (e.g. ground, buildings, trees, etc) can lead to multipath signals of similar signal power as the direct signal. This can result in deep nulls in the received signal power due to destructive interference. For narrow bandwidth transmissions if the null in the frequency response occurs at the transmission frequency then the entire signal can be lost. This can be partly overcome in two ways.

By transmitting a wide bandwidth signal or spread spectrum as CDMA, any dips in the spectrum only result in a small loss of signal power, rather than a complete loss. Another method is to split the transmission up into many small bandwidth carriers, as is done in a COFDM/OFDM transmission. The original signal is spread over a wide bandwidth thus; any nulls in the spectrum are unlikely to occur at all of the carrier frequencies. This will result in only some of the carriers being lost, rather then the entire signal. The information in the lost carriers can be recovered provided enough forward error corrections are sent.

Delay Spread:

The received radio signal from a transmitter consists of typically a direct signal, plus reflections of object such as buildings, mountings, and other structures. The reflected signals arrive at a later time than the direct signal because of the extra path length, giving rise to a slightly different arrival time of the transmitted pulse, thus spreading the received energy. **Delay spread** is the “time spread between the arrival of the first and last multipath signal seen by the receiver”.

In a digital system, the delay spread can lead to inter-symbol interference. This is due to the delayed multipath signal overlapping with the following symbols. This can cause significant errors in high bit rate systems, especially when using time division multiplexing (TDMA). **Fig** shows the effect of inter-symbol interference due to delay spread on the received signal. As the transmitted bit rate is increased the amount of inter-symbol interference also increases. The effect starts to become very significant when the delay spread is greater then ~50% of the bit time.

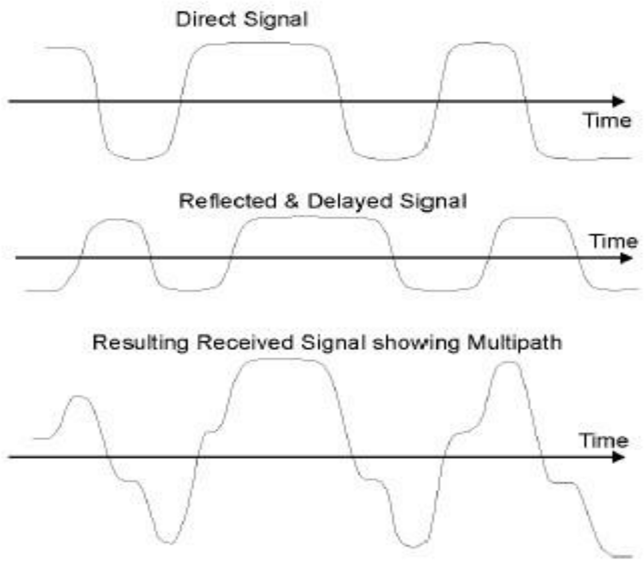

Fig.3.4 Multi delay spread

shows the typical delay spread that can occur in various environments. The maximum delay spread in an outdoor environment is approximately 20usec, thus significant inter symbol interference can occur at bit rates as low as 25kbps.

Table 3.3: Typical Delay Spread

Environment or cause	Delay Spread	Maximum Path Length Difference
Indoor (room)	40nsec - 200nsec	12m - 60 m
Outdoor	1usec - 20usec	300m - 6km

Inter-symbol interference can be minimized in several ways. One method is to reduce the symbol rate by reducing the data rate
for each channel (i.e. split the bandwidth into more channels using frequency division multiplexing). Another is to use a coding scheme which is tolerant to inter-symbol interference such as CDMA.

Doppler Shift:

When a wave source and a receiver are moving relative to one another the frequency of the received signal will not be the same as the source. When they are moving toward each other the frequency of the received signal is higher then the source, and when they are approaching each other the frequency decreases. This is called the

Doppler Effect. An example of this is the change of pitch in a car's horn as it approaches then passes by. This effect becomes important when developing mobile radio systems. The amount the frequency changes due to the Doppler effect depends on the relative motion between the source and receiver and on the speed of propagation of the wave. The Doppler shift in frequency can be written:

$$\Delta f \approx \pm f_o \frac{v}{c}$$

Where Δf is the change in frequency of the source seen at the receiver, *fo* is the frequency of the source, *v* is the speed difference between the source and transmitter, and *c* is the speed of light. For example: Let *fo* = 1GHz, and *v* = 60km/hr (16.7m/s) then the Doppler shift will be:

$$f_o = 10^9 \cdot \frac{16.67}{3\times10^8} = 55.5Hz$$

This shift of 55Hz in the carrier will generally not effect the transmission. However,

Doppler shift can cause significant problems if the transmission technique is sensitive to carrier frequency offsets (for example COFDM) or the relative speed is higher (for example in low earth orbiting satellites).

Inter Symbol Interference:

As communication systems evolve, the need for high symbol rates becomes more apparent. However, current multiple access with high symbol rates encounter several multi path problems, which leads to ISI. An echo is a copy of the original signal delayed in time. ISI takes place when echoes on different-length propagation paths result in overlapping received symbols. Problems can occur when one OFDM symbol overlaps with the next one. There is no correlation between two consecutive OFDM symbols and therefore interference from one symbol with the other will result in a disturbed signal

In addition, the symbol rate of communications systems is practically limited by the channel's bandwidth. For the higher symbol rates, the effects of ISI must be dealt with seriously. Several channel equalization techniques can be used to suppress the ISIs caused by the channel. However, to do this, the CIR – channel impulse response, must be estimated.

Recently, OFDM has been used to transmit data over a multi-path channel. Instead of trying to cancel the effects of the channel's ISIs, a set of **sub-carriers** can be used to transmit information symbols in parallel sub-channels over the channel, where the system's output will be the sum of all the parallel channel's throughputs.

This is the basis of how OFDM works. By transmitting in parallel over a set of sub-carriers, the data rate per sub-channel is only a fraction of the data rate of a conventional single carrier system having the same output. Hence, a system can be designed to support high data rates while deferring the need for channel equalizations.

In addition, once the incoming signal is split into the respective transmission subcarriers, a guard interval is added between each symbol. Each symbol consists of useful symbol duration, T_s and a guard interval, □t, in which, part of the time, a signal of T_s is cyclically

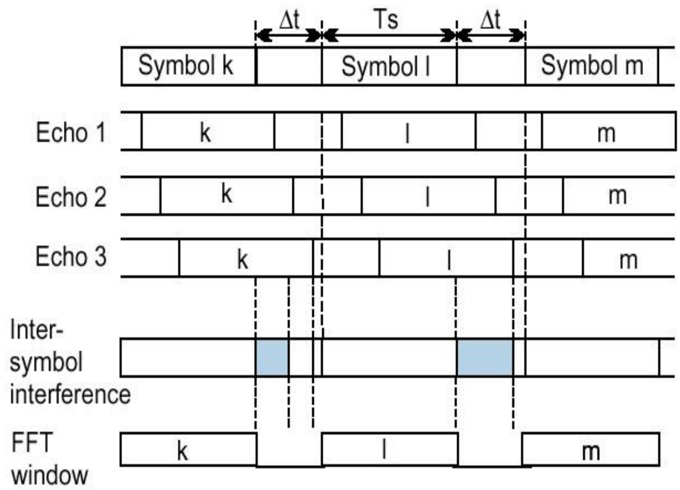

Fig. 3.5 Combating ISI using a guard interval

As long as the multi path propagation delays do not exceed the duration of the interval, no inter-symbol interference occurs and no channel equalization is required.

CHAPTER 5
EXISTING SYSTEM AND PROPOSED SYSTEM

5.1 EXISTING SYSTEM

MBSTBC-SM-LD

Space-time block codes (STBC) are a generalized version of Alamouti scheme, but have the same key features. These codes are orthogonal and can achieve full transmit diversity specified by the number of transmit antennas. In other words, space-time block codes are a complex version of Alamouti's space-time code, where the encoding and decoding schemes are the same as there in the Alamouti space-time code on both the transmitter and receiver sides. The data are constructed as a matrix which has its columns equal to the number of the transmit antennas and its rows equal to the number of the time slots required to transmit the data. At the receiver side, the signals received are first combined and then sent to the maximum likelihood detector where the decision rules are applied. Space-time block codes were designed to achieve the maximum diversity order for the given number of transmit and receive antennas subject to the constraint of having a simple linear decoding algorithm. This has made spacetime block codes a very popular and most widely used schemes. Training-based methods [4] seem to give very good results on the performance of channel estimation at the receiver. Pure training-based schemes can be considered as an advantage when an accurate and reliable MIMO channel needs to be obtained. However, this could also be a disadvantage when bandwidth efficiency is required. This is because pure training-based schemes reduce the bandwidth efficiency considerably due to the use of a long training sequence which is necessarily needed in order to obtain a reliable MIMO channel estimate. Because of the computation complexity of blind and semi-blind methods, many wireless communication systems still use pilot sequences to estimate the channel parameters at the receiver side.

The combiner shown in figure builds the following two combined signals that are sent to the maximum likelihood detector.

The encoder and decoder of the Alamouti schemes system is shown in Figure 2 and Figure 3. Here the information to be transmitted is modulated and fed to the space time encoder.

The space time encoder consists of two transmit antennas as part of the multiple input multiple output technology [6]. So here the information is transmitted through two separate antennas.

Each transmitting and the receiving antenna pair has a channel, represented by different channel coefficients. These channel coefficients play a major role in the design of the systEM. As the number of antennas increases at both the ends of the channel, the complexity of the systEM also increases.

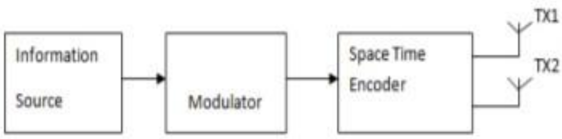

FIG:5.1 Space-time encoder

In the decoder, the received signal is fed to the channel estimator. The estimated coefficients of the channel together with the combiner are given as the input to the maximum likelihood detector. The detected signal is then fed to the demodulator. The demodulator gives the original information which is transmitted.

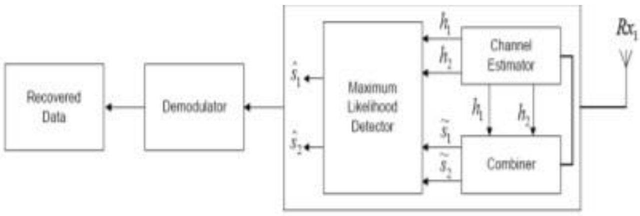

FIG:5.2 Space-time decoder

The space-time block codes are the higher version of the i.e, increment of the number of antennas of the scheme, the space-time block codes will result. As an example of the STBC’s, a case of 4 transmitted antennas and one receive antenna is explained here.

This systEM model of the MBSTBC-SM-LD systEM, having NR receive antennas and NT transmit antennas, over a fast frequency-flat Rayleigh fading channel. The channel gains of a fast fading channel are assumed to be constant during each time-slots and have independent values for different time slots. Each transmit antenna of MBSTBC-SM-LD is equipped with mrf RF mirrors. Furthermore, the transmission of the MBSTBC-SM-LD symbols Employ two time-slots, which shall be referred to as Time-slot A and Time-slot

B, for the first and second time-slots, respectively. The systEM model of the proposed NR × NT MBSTBC-SM-LD over a fast, frequency-flat Rayleigh fading channel, having mrf RF mirrors is presented in Section III. In Section IV, the theoretical union bound on the average bit error probability for the ML detector of the proposed MBSTBC-SMLD over an independent and identically distributed disadvantages

- However, SM is not able to achieve diversity.
- Furthermore, SM is able to reduce power consumption because it Employs a single RF chain. Since SM Employs a single antenna, it is not able to eliminate inter-symbol interference and inter channel interference.

5.2 PROPOSED SYSTEM

SPACE-TIME MEDIA BASED MODULATION

In this paper, an innovative concept based on the framework of SSK and MBM schemes, called space-time media-based modulation (ST-MBM), is proposed by cleverly combining the Hurwitz-Radon family of matrices [32] with the MBM transmission approach. The proposed ST-MBM scheme is the first STBC-based scheme that achieves transmit diversity gains by using a single RF chain with a significantly lower receiver complexity. Theoretical error performance analysis of the proposed ST-MBM scheme is performed and its exact average bit error probability (ABEP) is derived for correlated and uncorrelated channel states. Furthermore, a lower bound is obtained for the mutual information of the ST-MBM scheme. Through comprehensive computer simulations, bit error rate (BER) performance of ST-MBM scheme is compared with the existing state-of-the-art MIMO concepts in the literature.

Multi-user MIMO (MU-MIMO) can leverage multiple users as spatially distributed transmission resources, at the cost of somewhat more expensive signal processing. In comparison, conventional, or single-user MIMO considers only local device multiple antenna dimensions. Multi-user MIMO algorithms are developed to enhance MIMO systems when the number of users or connections is greater than one. Multi-user MIMO can be generalized into two categories: MIMO broadcast channels (MIMO BC) and MIMO multiple access channels (MIMO MAC) for downlink and uplink situations, respectively. Single-user MIMO can be represented as point-to-point, pair wise MIMO

An efficient way to compensate the inherently low spectral efficiency of STBC-based systems is to carry as much information as possible via the indices of the building blocks of the target transmission systEM. For a MIMO-MBM transmission scheme, the available building blocks for indexing are transmit antennas and RF mirrors. Beside these, in the proposed STMBM scheme, in order to further improve the spectral efficiency, information bits are subdivided into N transmission groups and space-time coding principle is independently applied to these transmission groups. In this project, an innovative concept based on the framework of SSK and MBM schemes, called space-time media-based modulation (ST-MBM), is proposed by cleverly combining the Hurwitz-Radon family of matrices with the MBM transmission approach. Multi-user MIMO (MU-MIMO) can leverage multiple users as spatially distributed transmission resources, at the cost of somewhat more expensive signal processing. In comparison, conventional, or single-user MIMO considers only local device multiple antenna dimensions. Multi-user MIMO algorithms are developed to enhance MIMO systems when the number of users or connections is greater than one. Multi-user MIMO can be generalized into two categories: MIMO broadcast channels (MIMO BC) and MIMO multiple access channels (MIMO MAC) for downlink and uplink situations, respectively. Single-user MIMO can be represented as point-to-point, pair wise MIMO.

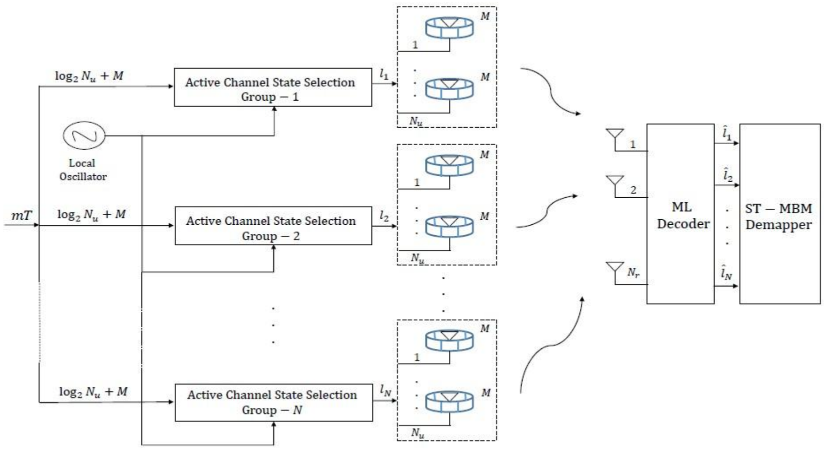

FIG:5.3 Block diagram of the ST-MBM scheme.

To remove ambiguity of the words receiver and transmitter we can adopt the terms access point (AP; or, base station), and user. An AP is the transmitter and a user is the receiver for downlink environments, whereas an AP is the receiver and a user is the transmitter for uplink environments. Homogeneous networks are somewhat freed from this distinction.

1.7 SPACE DIVISION MULTIPLE ACCESS

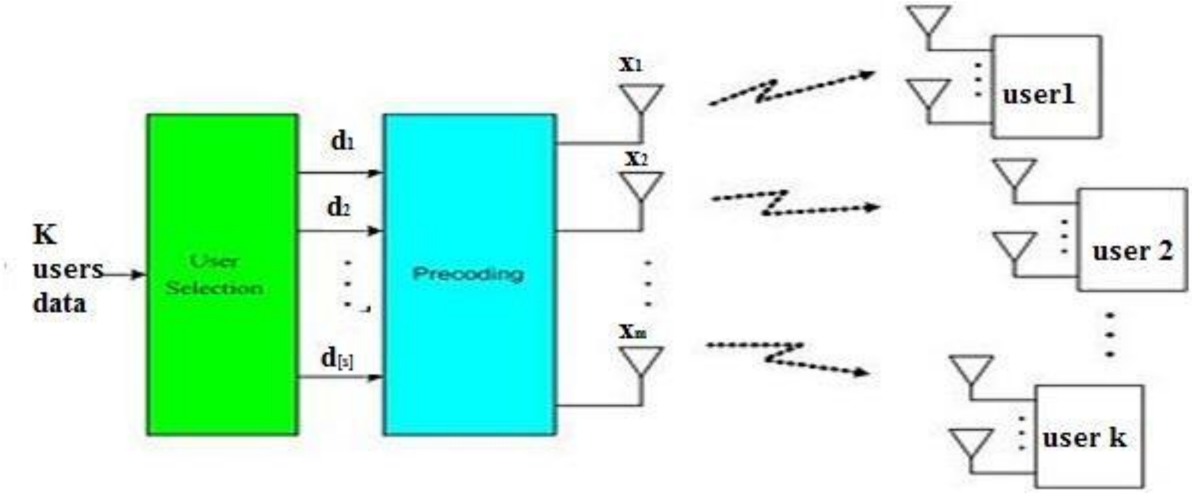

Fig: 5.4 Space Division Multiple Access

MIMO broadcast represents a MIMO downlink case in a single sender to multiple receiver wireless networks. Examples of advanced transmit processing for MIMO BS are interference aware precoding and SDMA-based downlink user scheduling. For advanced transmit processing, the channel state information has to be known at the transmitter (CSIT). That is, knowledge of CSIT allows throughput improvement, and methods to obtain CSIT become of significant importance. MIMO BS systems have an outstanding advantage over point-to-point MIMO systems, especially when the number of transmit antennas at the transmitter, or AP, is larger than the number of receiver antennas at each receiver (user) as shown in fig 1.2. Two categories of coding techniques for the MIMO BC include those using dirty paper coding and linear techniques[7].

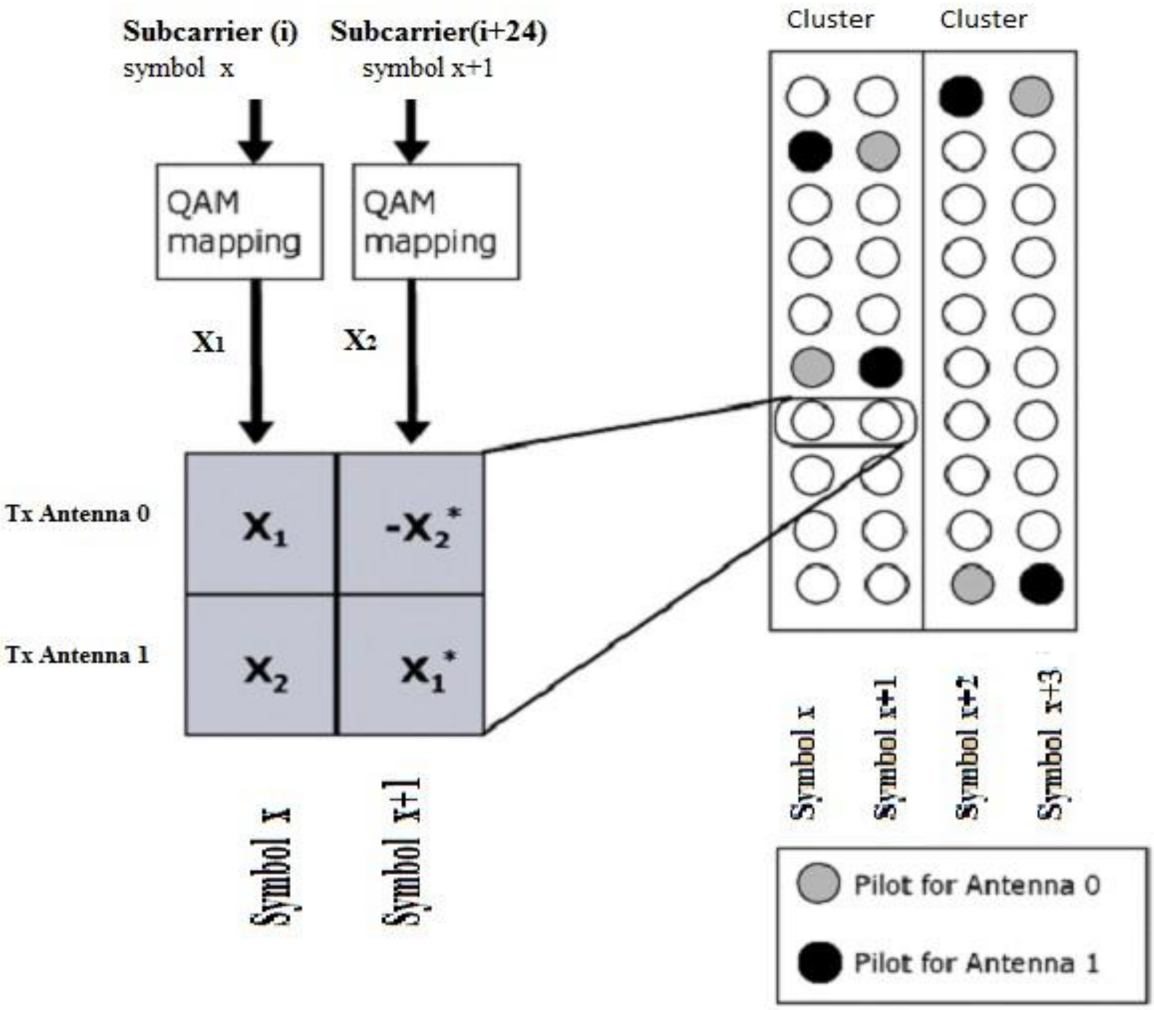

Fig 5.5 Space time decoding

Space time codes may be split into two main types

- Space–time trellis codes (STTCs) [1] distribute a trellis code over multiple antennas and multiple time-slots and provide both coding gain and diversity gain.
- Space–time block codes (STBCs) [2][3] act on a block of data at once (similarly to block

  codes) and also provide diversity gain but doesn't provide coding gain.

STC may be further subdivided according to whether the receiver knows the channel impairments. In coherent STC, the receiver knows the channel impairments through training or some other form of estimation. These codes have been studied more widely, and division algebras [4] over number fields have now become the standard tool for constructing such codes .In non-coherent STC the receiver does not know the channel impairments but knows the statistics of the channel.[5] In differential space–time codes neither the channel nor the statistics of the channel are available.

The proposed ST-MBM scheme is the first STBC-based scheme that achieves transmit diversity gains by using a single RF chain with a significantly lower receiver complexity. Theoretical error performance analysis of the proposed ST-MBM scheme is performed and its exact average bit error probability (ABEP) is derived for correlated and uncorrelated channel states. Furthermore, a lower bound is obtained for the mutual information of the ST-MBM scheme.

$$\frac{mT}{N} = \log_2(N_u) + M \quad \text{..(1)}$$

bits are transmitted, where Nu = Nt/N is defined as the number of transmit antennas in the uth transmission group, for u ∈ {1, 2, . . . , N}. In each group, the first log2 Nu bits of the incoming log2 (Nu) + M bits determine the index of the active transmit antenna, which is selected out of Nu available transmit antennas, while the following M bits specify one of the available 2M channel states corresponding to this active antenna. It can be alternatively expressed that in each transmission group, one of the available Pu = Nu2M channel fade realizations, which are created jointly by reconfigurable antennas and the SSK concept, is selected by the incoming log2 (Pu) bits. Therefore, the total number of channel fade realizations through N transmission groups becomes P = NPu, and the spectral efficiency of the ST-MBM scheme in bits per channel use (bpcu) is given as

$$m = \frac{N\left[M + \log_2(N_u)\right]}{T} = \frac{N\log_2(P_u)}{T} \quad \text{............(2)}$$

due to the use of T time slot. The signaling structure of the proposed scheme in T time slots will be explained next. For each transmission group, the incoming bits determine the transmission vector of the first time slot. This corresponds to an SSK vector, since no information is conveyed through the selected channel state by means of amplitude/phase modulations. Therefore, the transmission vector of the first time slot related to transmission group u can be given a where lu denotes the index of the specified channel fade realization of the first time slot among Pu channel fade realizations in the uth transmission group, and lu ∈ {1, 2, . . . , Pu}. Then, the overall transmission matrix of each group is formed by the following structure of the Hurwitz-Radon family of matrices, where a detailed discussion is given below. At the receiver side, in order to perceive complex Gaussian distributed random variables as in the case of SSK/MBM and, at the same time, to obtain transmit diversity gain, the HurwitzRadon family of matrices [32], a set of L × L real orthogonal matrices whose each row and column corresponds to an SSK vector, are used as core STBCs. For lu ∈ {1, 2, . . . , L}, each set of these L × L Hurwitz-Radon matrices satisfies the following conditions

$$\begin{aligned} &\mathbf{B}_{l_u}{}^T\mathbf{B}_{l_u} = \mathbf{I}_L \quad l_u = 2, \ldots, L \\ &\mathbf{B}_{l_u}{}^T = -\mathbf{B}_{l_u} \quad l_u = 2, \ldots, L \\ &\mathbf{B}_{l_u}\mathbf{B}_{l_u'} = -\mathbf{B}_{l_u'}\mathbf{B}_{l_u} \quad 1 \leq l_u < l_u' \leq L \end{aligned} \qquad \text{........(3)}$$

where B1 = IL and L ∈ {2, 4, 8}. For L = 4, the Hurwitz-Radon matrices satisfying (4) are given a Similarly, the following Hurwitz-Radon matrices are constructed for L = 8 where B1 = I8. It is worth noting that real-orthogonal STBCs are constructed by using the above Hurwitz-Radon matrices [32]. In the proposed ST-MBM scheme, after specifying the transmission vectors of the first time slot for each of N transmission groups (3), the HurwitzRadon matrices are independently exploited for each group as the core STBCs to construct the overall transmission matrix. For Pu = T = L, the rows and columns of the Hurwitz-Radon matrices are considered for T time slots and Pu channel fade realizations, respectively. Let us introduce the ST-MBM concept for Pu = T with the following example, while the generalized ST-MBM concept for larger channel fade realizations of Pu > 8 will be given in the next subsection. Example: Assume that Pu = 4 channel fade realizations are generated in each of N = 2 transmission groups, where Nt = 4 transmit antennas are equipped with a single (M = 1) RF mirror. In this setup, spreading the signal transmission takes place in T = 4 time slots. For this case, a spectral efficiency of m = 1 bpcu is achieved, where Nu = Nt/N = 2 and u ∈ {1, 2}. Suppose that incoming mT = 4 bits of {1 0 0 1} are transmitted over N = 2 transmission groups, where the first two {1 0} bits are assigned to the first group and the remaining {0 1} bits are assigned to the second group. In the first group, the first {1} bit of {1 0} bit sequence activates one of N1 = 2 transmit antennas while the follow in {0} bit selects one of 2M = 2 channel states generated with M = 1 RF mirror, which corresponds to the first channel state of the second transmit antenna. It can be alternatively stated that the bit sequence of {1 0} specifies the third channel fade realization (l1 = 3) among P1 = N12M = 4 channel fade realizations. Similarly, for the second group, the first {0} bit of remaining {0 1} bits activates the first transmit antenna of the second antenna group, where N2 = 2, while the following {1} bit determines the second channel state of the corresponding active antenna. In other words, the second (l2 = 2) out of P2 = N22M = 4 channel fade realizations is selected. For the rEMaining three time slots, we follow the HurwitzRadon matrices in (5) to obtain a diversity gain. Therefore, transmission matrices of the first and second groups can be given as

$$\mathbf{X}_1 = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{bmatrix}, \quad \mathbf{X}_2 = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \qquad ....(4)$$

which respectively correspond to B3 and B2 in (5). Then, the overall transmission matrix, that comprises both X1 ∈ C T ×P1 and X2 ∈ C T ×P2 , is given as

$$\mathbf{X} = \left[\begin{array}{cccc|cccc} 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & -1 & 0 & 0 & 0 & 0 & 1 & 0 \end{array}\right]. \qquad ....(5)$$

We note that the rows and columns of X ∈ C T ×P correspond to time slots and channel fade realizations, respectively. Since the overall transmission matrix is formed by the elements of {1, −1, 0} in the baseband, to transmit these elements, a single RF chain is sufficient. Then, as given in Fig. 1, a cosine carrier signal generated from a local oscillator is supplied to N groups to transmit 1s and −1s. Thus, as the traditional SM/SSK systems [33], the overall STMBM systEM has been designed by using a single RF chain.

Transmit Diversity Analysis

The rank and determinant criteria are commonly used in the design of STBCs to maximize diversity and coding gains. Let us consider the transmit STBC matrix Si and the erroneously detected STBC matrix Sj , for i 6= j, then transmit diversity gain Gd is evaluated as

$$G_d = \text{rank}\left[(\mathbf{S}_i - \mathbf{S}_j)(\mathbf{S}_i - \mathbf{S}_j)^H\right].$$ **.......................(6)**

The maximum transmit diversity order that can be achieved by any T × Pu orthogonal STBC is equal to the number of time slots T, which is respectively four and eight for the square STBC matrices given in (5) and (6). However, since there is only one non-zero elEMent in each row and column of the Hurwitz-Radon matrices, rEMoving any row(s) or column(s) results in a new orthogonal design, which does not violate the orthogonality of the rEMaining matrix and allows us to achieve any transmit diversity order of Gd = T for T ≤ 8. In the ST-MBM schEMe, since the Hurwitz-Radon matrices are utilized as core STBC matrices, we take the advantage of this unique property and in the same way, can achieve a transmit diversity order of T, where 2 ≤ T ≤ 8, by rEMoving the required number of row(s) from the overall ST-MBM transmission matrix. Accordingly, in the ST-MBM schEMe, when the transmit signal matrix X is erroneously detected as Xˆ , the transmit diversity order of the ST-MBM schEMe is given as:

$$G_d = \text{rank}\left[(\mathbf{X} - \hat{\mathbf{X}})(\mathbf{X} - \hat{\mathbf{X}})^H\right] = T.$$ **.....................................(7)**

Furthermore, considering the above rank criterion, inserting an all-zero matrix to any STBC matrix, without distorting the integrity of the target matrix, still does not violate the orthogonality of the core STBC, and the newly generated STBC matrix achieves the same transmit diversity as that of the core STBC. This allows us to generalize the STMBM schEMe for more than eight channel fade realizations (Pu > 8), which exceeds the maximum dimensions of the Hurwitz-Radon matrix, and to attain higher spectral efficiency values while still achieving a transmit diversity order of T ≤ 8. In each transmission group, since Pu = Nu2M > 8 is also an integer multiple of 8, to retain the orthogonality of the core STBC, the required number of T × 8 all-zero matrices are added to the core T × 8 STBC matrix, and the corresponding transmission matrix is generated by shifting the core STBC matrix in blocks in accordance with the index of active channel state lu, where lu ∈ {1, 2, . . . , Pu}. Therefore, for Pu > 8, the overall transmission matrix of uth transmission group, Xu ∈ C T ×Pu , can be given as

$$\mathbf{X}_u = [\mathbf{0}_8 \ \cdots \ \mathbf{0}_8 \ \mathbf{B}_{l_u} \ \mathbf{0}_8 \ \cdots \ \mathbf{0}_8]$$ **..(8)**

where y ∈ C T Nr×1 = vec(Y), w ∈ C T Nr×1 = vec(W), hχ ∈ C T Nr×1 = vec(XH) and hu ∈ C T Nr×1 is a column vector that contains channel fade realizations corresponding to non-zero elEMents of Xu, the transmission matrix of the uth transmission group. At the receiver side, assuming perfect channel state information (P-CSI), the equivalent signal model of (14) is considered and a maximum likelihood (ML) detector is used to achieve the optimum BER performance as

$$\left(\hat{l}_1, \hat{l}_2, \ldots, \hat{l}_N\right) = \arg \min_{l_1, l_2, \ldots, l_N} \left\| \mathbf{y} - \sum_{u=1}^{N} \mathbf{h}_u \right\|^2 .$$ **..(9)**

Then, the overall computational complexity of the ML detector (15) is evaluated in terms of real multiplications as ∼ O(T Nr2 mT +1), since each of 2 mT decision metric calculations requires 2T Nr real multiplications for each k·k2 operation.

PERFORMANCE AND CAPACITY ANALYSES

In this section, based on our systEM model of Section II, we present error performance and capacity analyses for the proposed ST-MBM schEMe. In the ST-MBM schEMe, correlated and uncorrelated fading channels are considered and the correlated channel matrix H is modeled through the uncorrelated Rayleigh fading channel matrix ~H 2 CP_Nr, whose elEMents are i.i.d. complex Gaussian random variables with distribution

$$\mathbf{H} = \mathbf{R}_t^{1/2} \tilde{\mathbf{H}} \mathbf{R}_r^{1/2}.$$

where Rt and Rr denote transmit and receive correlation matrices with dimensions of P _P and Nr_Nr, respectively. In this study, the transmit correlation matrix Rt is determined by considering two different correlation models: the Kronecker model [34] and the equi correlation model [14]. The Kronecker model is used for the correlation among the fades of different transmit antennas, while the equi correlation model is considered for the correlation among the channel states of each transmit antenna. Rt is given in (17), where ra and rb are the correlation coefficients between the transmit antennas and channel states, respectively. On the other hand, the receive correlation matrix Rr is characterized by using the Kronecker model **Performance Analysis**

In this subsection, the theoretical ABEP performance of the ST-MBM schEMe is analyzed. Considering a commonly used upper bounding technique [35], the ABEP of the systEM is given as

$$P_b \leq \frac{1}{2^\kappa} \sum_{\mathbf{X}} \left[\frac{1}{\kappa} \sum_{\hat{\mathbf{X}}} Pr\left(\mathbf{X} \rightarrow \hat{\mathbf{X}}\right) e\left(\mathbf{X}, \hat{\mathbf{X}}\right) \right]$$

where _ is the number of incoming bits, i.e., _ = mT, Pr(X ! ^X) is the pairwise error probability (PEP) and e(X; ^X) is the number of bit errors occurred for the corresponding pair wise error event.

Capacity Analysis

The amount of information conveyed between the transmission vector x and the received vector y is defined as the mutual information and is given for the MIMO channel matrix H as

$$I(\mathbf{y};\mathbf{x}) = \mathbb{E}_{\mathbf{H}}\Big\{H(\mathbf{y}|\mathbf{H}) - H(\mathbf{y}|\mathbf{x},\mathbf{H})\Big\}.$$

However, for the ST-MBM schEMe, when the equivalent signal model (14) of the ST-MBM is considered, since incoming information bits modulate channel elEMents and carry no information with an ordinary modulation, the mutual information is defined as amount of information conveyed between the received signal y and the channel vector .

The conditional probability density function of the equivalent received signal vector of is given by

$$P(\mathbf{y}|\mathbf{h}\chi) = \frac{1}{(\pi N_0)^{TN_r}} \exp\left(-\frac{\|\mathbf{y}-\mathbf{h}\chi\|^2}{N_0}\right).$$

mutual information of the ST-MBM schEMe using T time slots, I(y; h_), results in (36), where the factor of 1=T comes from T channel uses. Then, using the Jensen’s inequality and applying some algebraic manipulations [38], a lower bound is obtained.

CHAPTER 6

RESULTS

MATLAB SIMULATIONS

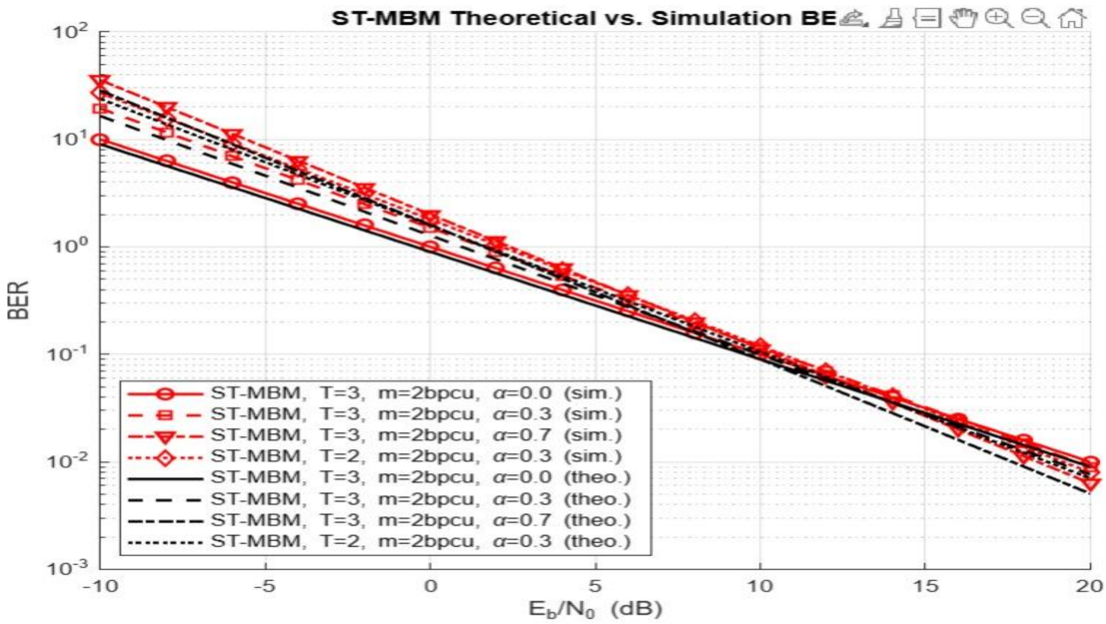

Fig.6.1.TheoreticalandsimulationresultsoftheST-MBMschEMeforT=2 andT=3underdifferentchannelcorrelationvalues

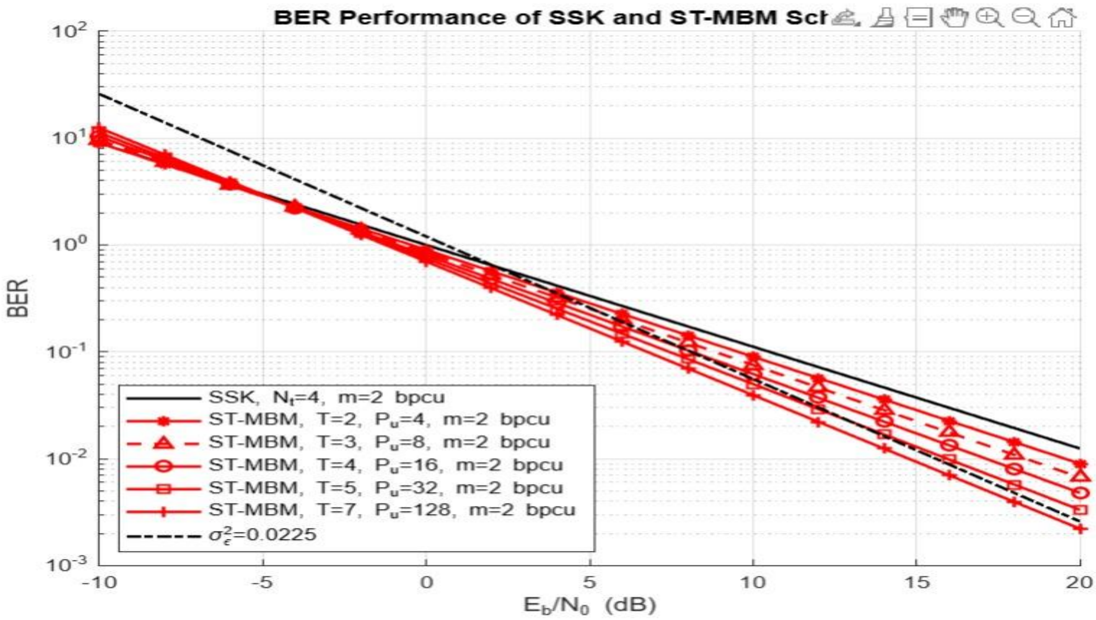

Fig. 6,2. BERperformance of the SSKand ST-MBMschEMes for T∈ n{2,3,4,5,7}andm=2bpcuwithperfectandimperfectchannelestimation.

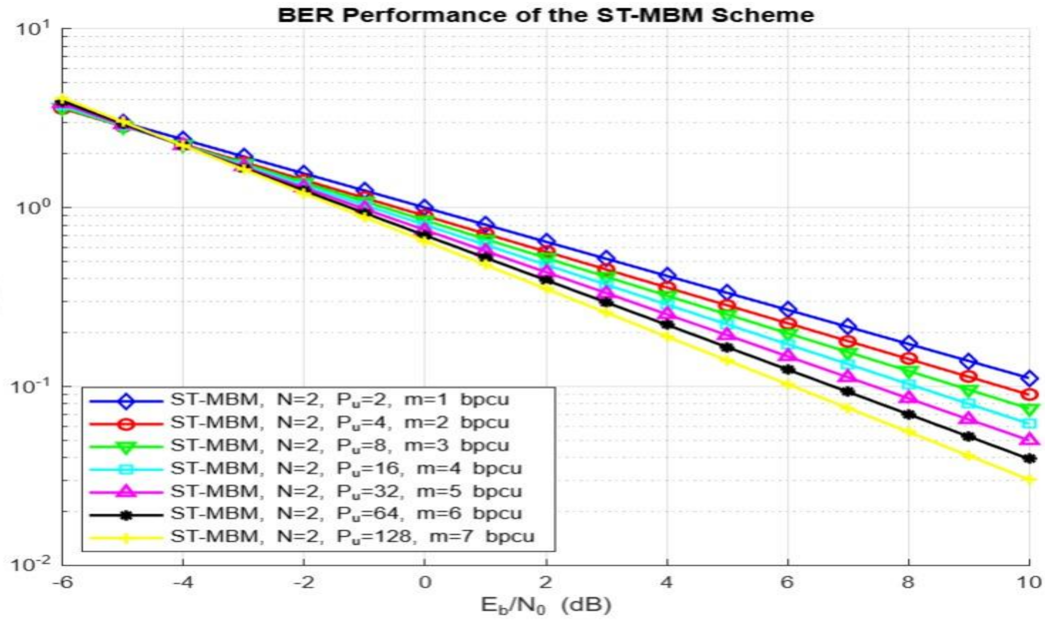

Fig 6.3. BER performance of the ST-MBM schEMe for T =2and m = 1, 2,3,4,5,6,7 bpcu

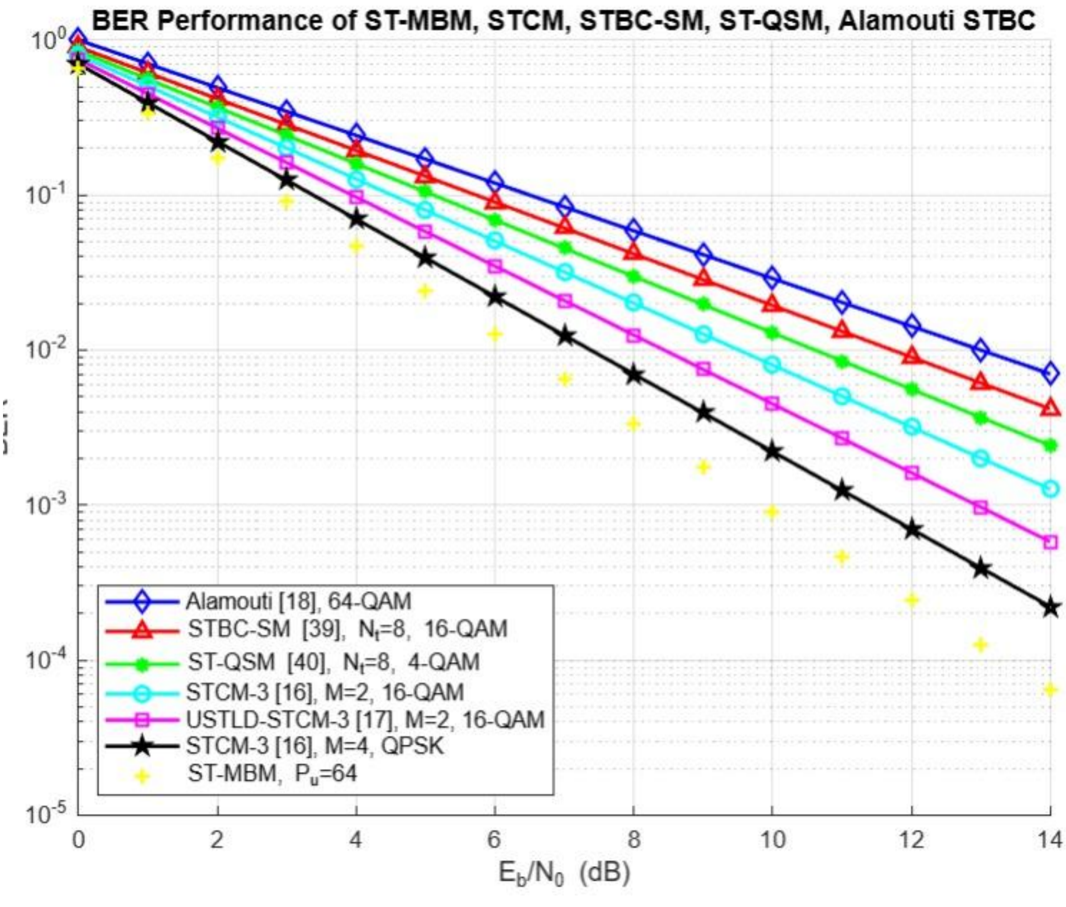

Fig 6.4. BER performance of ST-MBM, STCM [16], USTLD-STCM [17], STBC-SM [39], ST QSM [40], Alamouti's STBC [18] and SSK schemes for m=6bpc

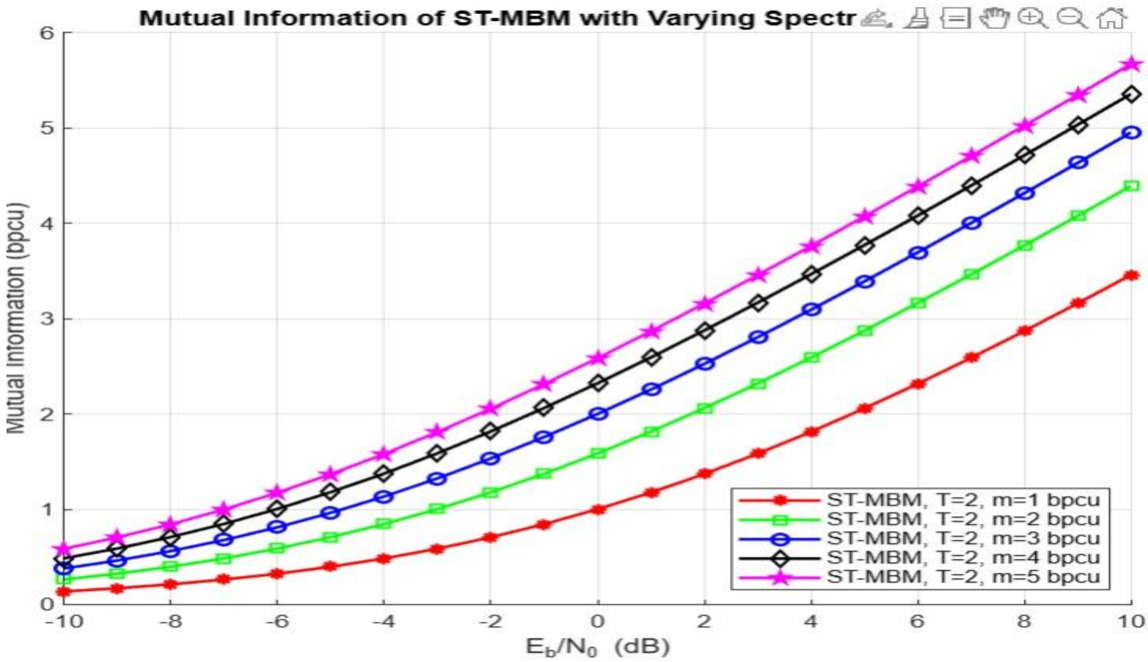

Fig 6.5. Mutual information of the ST-MBM scheme with varying spectral efficiencies for T =2

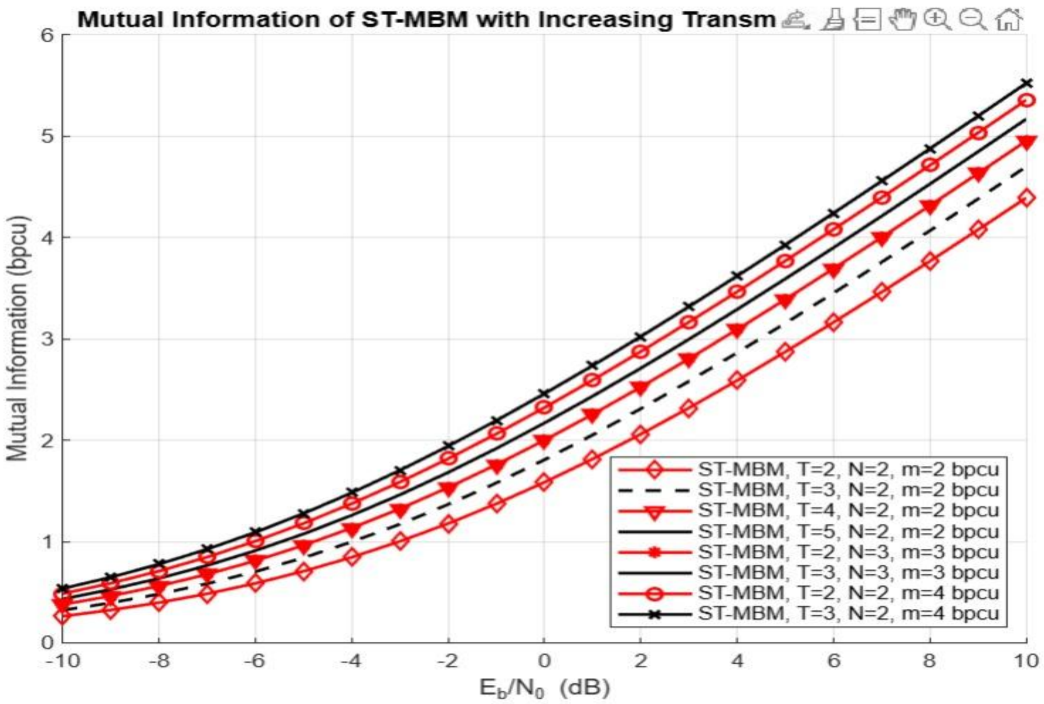

Fig 6.5. Mutual information of the ST-MBM scheme with increasing transmit diversity orders for m = 2, 3 and 4 bpcu

CHAPTER 7

CONCLUSION

- In this paper, we have presented a general framework for space-time coded IM systEMs and introduced the ST-MBM schEMe as the first STBC-based transmission schEMe that uses a single RF chain at the transmitter while achieving various transmit diversity gains through MBM and time dispersion.
- Theoretical error performance analysis of the ST-MBM schEMe for correlated and uncorrelated channel fading has been investigated. Additionally, a lower bound has been derived for the mutual information of the ST-MBM schEMe. Furthermore, through ex tensive computer simulations, the superior error performance of the proposed ST-MBM schEMe with significantly lower decoding complexity over existing STBC-based transmission schEMes has been dEMonstrated.
- The flexibility to achieve higher spectral efficiencies and various transmit diversity gains makes the ST-MBM schEMe highly suitable for beyond 5G and ultra reliable low-latency communications (URLLC) applications. Our future work will focus on the enhancEMent of the proposed ST-MBM schEMe through the use of multiple RF chains and/or ordinary modulations, low-complexity detection algorithms as well as performance analysis of the proposed systEM over poorly scattered milli meter wave (mm Wave) channels.

7.1 APPLICATIONS

1. Wireless Communication SystEMs

- **Multiple-Input Multiple-Output (MIMO) SystEMs:** One of the most prominent applications is in MIMO systEMs, which are widely used in Wi-Fi, 4G, and 5G networks. Space-time media-based modulation improves data throughput and reliability by exploiting multiple antennas at both the transmitter and receiver.
- **Orthogonal Frequency Division Multiplexing (OFDM):** In systEMs like 4G LTE and Wi-Fi, space-time modulation is often combined with OFDM for more robust and efficient wireless communication. It helps mitigate signal fading and interference, leading to higher data rates and more stable connections.

2. 5G and Beyond

- **Enhanced Mobile Broadband (EMBB):** Space-time modulation plays a key role in meeting the high-speed requirEMents of 5G EMBB applications, ensuring high data throughput for video streaming, virtual reality, and augmented reality.
- **Ultra-Reliable Low Latency Communications (URLLC):** For mission-critical applications that require ultra-reliable and low-latency communication, such as autonomous vehicles or industrial IoT systEMs, space-time media-based modulation helps maintain the stability and reliability of communication links, even in adverse conditions.
- **Massive Machine-Type Communications (mMTC):** Space-time modulation enables efficient communication between a large number of devices, such as in smart cities, connected cars, or industrial sensors, where reliability and low-power consumption are essential.

3. Satellite Communication

- **Inter-Satellite Links (ISLs):** Space-time modulation can improve communication between satellites in low Earth orbit (LEO) and geostationary satellites (GEO), ensuring efficient data transfer for satellite constellations like Starlink. It allows for high-speed communication, even in the presence of fading and interference.

- **Deep-Space Communication:** Space-time modulation is used to enhance communication with space probes and rovers. In environments with extrEMe distance and signal degradation, space-time coding schEMes help maintain a reliable signal for data transmission from space missions to Earth.
- **Global Internet Coverage:** By enhancing the robustness of satellite communication links, space-time media-based modulation supports the growing dEMand for global internet coverage, especially in rEMote areas where terrestrial networks are limited.

4. Cognitive Radio Networks

- **Dynamic Spectrum Access:** Space-time modulation is crucial in cognitive radio networks (CRNs), where devices dynamically adapt to available spectrum. It allows for better spectrum utilization, helping secondary users avoid interference with primary users while ensuring reliable communication.
- **Interference Mitigation:** In crowded wireless environments, space-time modulation techniques help reduce interference by making better use of the spatial and tEMporal properties of the wireless channel. This leads to more stable connections in dense urban areas or in networks with high user densities.

5. Wireless Sensor Networks (WSNs) and Internet of Things (IoT)

- **Low-Power and Reliable Communication:** Space-time media-based modulation is highly useful for IoT and WSNs, which require energy-efficient communication protocols. By improving the reliability and energy efficiency of communication, it helps extend the battery life of IoT devices while maintaining high data reliability.
- **Large-Scale Deployments:** In large-scale deployments of connected devices (e.g., smart agriculture, smart homes), space-time modulation techniques enable scalable communication solutions, ensuring that all devices can communicate effectively even in harsh or complex environments.

6. Autonomous Vehicles

- **Vehicle-to-Vehicle (V2V) Communication:** Space-time modulation plays a critical role in enhancing the reliability of V2V communications, ensuring that autonomous vehicles can exchange data about their positions, speed, and other critical information in real-time, especially in areas with high interference or multipath effects.

- **Vehicle-to-Infrastructure (V2I) Communication:** It also ensures stable communication between vehicles and infrastructure (like traffic lights or smart road signs), which is essential for the safe operation of self-driving vehicles.

7. Military and Defense Applications

- **Robust Tactical Communication:** In military operations, especially in challenging environments like urban warfare or rEMote locations, space-time modulation improves the robustness of communication links. It helps maintain reliable and secure communication channels in the presence of jamming, interference, and signal degradation.

- **Secure Communication Networks:** Space-time modulation also enhances the security of communication networks by making it harder for adversaries to intercept or disrupt signals, providing secure and high-quality communication for defense operations.

8. Wireless Backhaul Networks

- **High-Speed Backbone Links:** Space-time modulation is used in wireless backhaul networks, which connect base stations or other network infrastructure. It allows for high-speed data transfer, particularly in areas where fiber-optic cables are not feasible due to geographical challenges or cost.

- **Microwave Communication:** For point-to-point microwave communication, space-time modulation ensures the reliability of the link by compensating for atmospheric disturbances, rain fade, and other environmental factors that might otherwise affect signal quality.

9. Healthcare and REMote Monitoring

- **Medical TelEMetry:** Space-time modulation is beneficial in healthcare systEMs that rely on rEMote patient monitoring or telEMedicine. By improving the reliability of wireless communication in medical environments, it ensures that vital data from patient monitoring devices can be transmitted accurately and in real-time to healthcare providers.

- **Wearable Devices:** For wearable health devices, which need to transmit data over wireless channels, space-time modulation can ensure a more reliable and energy-efficient communication process, which is critical for devices that require long battery life.

7.2 ADVANTAGES

1. Improved Signal Reliability

- **Diversity Gain:** One of the major advantages of space-time media-based modulation is its ability to exploit **spatial diversity**. By using multiple antennas at both the transmitter and receiver (as in MIMO systEMs), the systEM can overcome the effects of fading and interference. This leads to improved reliability of the signal, especially in environments with severe signal degradation (such as urban or mountainous regions).
- **Error Rate Reduction:** By using space-time codes, the modulation can reduce bit error rates (BER) and improve the quality of the received signal, ensuring more stable and consistent communication.

2. Increased Data Rates

- **Higher Capacity:** Space-time media-based modulation can increase the data transmission rate by utilizing multiple channels in the spatial domain (via multiple antennas). This allows systEMs to transmit more data simultaneously, leading to higher overall throughput and efficient use of available spectrum.
- **Support for High-Speed Applications:** The enhanced data rates enable the support of bandwidth-hungry applications such as video streaming, online gaming, and virtual/augmented reality, especially in 4G, 5G, and future communication systEMs.

3. Enhanced Coverage and Range

- **Improved Coverage:** By using multiple antennas and space-time coding techniques, space-time modulation improves the overall **coverage area** of a wireless systEM. It helps maintain a robust signal over a wider area, reducing the likelihood of signal dropouts, especially in areas with weak signal reception or in outdoor environments.
- **Increased Range in Harsh Environments:** In rEMote or challenging environments (e.g., rural areas, urban canyons, and mountainous terrains), space-time modulation can help extend the effective communication range by mitigating the effects of path loss and shadowing.

4. Interference Mitigation

- **Reduced Interference:** Space-time modulation can significantly reduce the impact of interference in wireless communication. This is particularly important in crowded wireless environments where multiple devices are transmitting simultaneously. The technique exploits spatial diversity, making it more resistant to interference from other users or devices.
- **Multipath Mitigation:** Space-time media-based modulation can also combat **multipath fading**, where signals arrive at the receiver via multiple paths, causing interference. The technique utilizes multiple antennas and time-based coding to improve the reception and reconstruction of signals, even in complex multipath environments.

5. Improved Energy Efficiency

- **Low Power Consumption:** By enabling higher data rates and more robust communication with fewer retransmissions, space-time modulation can enhance the energy efficiency of wireless communication systEMs. This is especially beneficial for devices operating on limited power, such as Internet of Things (IoT) devices, wireless sensors, and mobile devices.
- **Extended Battery Life for IoT Devices:** For battery-powered IoT devices or sensors, space-time modulation ensures reliable communication with reduced energy consumption, leading to longer operational lifetimes without frequent recharging or battery replacEMent.

6. Scalability in Network Design

- **Support for Dense Networks:** In scenarios where multiple devices are connected within a network (e.g., smart cities or industrial IoT), space-time modulation allows the systEM to scale efficiently. By enhancing spectral efficiency, it can support more users and devices without sacrificing performance, even in highly congested environments.
- **Flexible Network Expansion:** Space-time modulation also allows for better use of available spectrum, which is crucial for the scalable expansion of networks,

particularly in systEMs like 5G, where a large number of connected devices need to be supported.

7. Improved Spectral Efficiency

- **Optimized Spectrum Usage:** By utilizing multiple antennas and the space-time characteristics of the wireless channel, space-time modulation improves the **spectral efficiency** of the systEM. This means that more data can be transmitted over a given bandwidth, making better use of the available spectrum and reducing the need for additional frequency allocations.
- **Support for Higher Frequency Bands:** As wireless networks move to higher frequency bands (e.g., millimeter-wave frequencies for 5G), space-time modulation techniques are essential for maintaining signal quality and throughput. These higher frequencies are more susceptible to fading and interference, and space-time modulation helps counteract these effects.

8. Enhanced Security

- **Secure Transmission:** Space-time modulation can improve the security of wireless communication. By spreading the transmitted signal over multiple antennas and time slots, it becomes more difficult for unauthorized users to intercept or decode the signal. This can provide a layer of **security through diversity** and make it harder for eavesdroppers to break into communication links.
- **Resistance to Jamming:** The technique can also enhance the robustness of communication systEMs against jamming attacks. Because the signal is spread across space and time, it becomes more resilient to jamming efforts that target specific frequencies or channels.

9. Better Handling of Channel Variability

- **Adaptive to Changing Channels:** Space-time media-based modulation allows the systEM to dynamically adapt to changing wireless channels. As the environment changes (due to mobility, weather, or user behavior), the modulation can be adjusted to optimize performance, ensuring a continuous and stable connection even in highly dynamic conditions.

- **Better Performance in Fading Environments:** In environments where the channel quality fluctuates over time (e.g., due to weather conditions or movEMent), space-time coding techniques help mitigate fading effects, improving performance in both fast and slow fading scenarios.

10. Support for Multiple Communication Standards

- **Interoperability:** Space-time modulation can be applied across various wireless standards, including LTE, Wi-Fi, 5G, and even future communication technologies. This allows for seamless integration of systEMs with different requirEMents and capabilities, enabling interoperability between different networks and devices.
- **Cross-Layer Optimization:** The flexibility of space-time media-based modulation allows for optimization across multiple layers of the communication protocol stack, improving the overall performance of end-to-end communication systEMs.

CHAPTER 8
FUTURE SCOPE

1. Enhanced Data Transmission Rates

- **Advanced Modulation Techniques:** Space-time media-based modulation can facilitate higher data rates through more sophisticated encoding and decoding schemes. Future research might focus on combining space-time codes with newer modulation techniques such as higher-order quadrature amplitude modulation (QAM) and multi-carrier systems to push the limits of data transmission speeds.
- **5G and Beyond:** As wireless communication evolves with 5G and beyond, space-time modulation schemes could be critical in meeting the growing demand for faster and more reliable connections. For example, multi-layered space-time codes and advanced beamforming will be central to the efficient use of spectrum and energy.

2. Improved Robustness and Reliability

- **Channel Adaptation:** Future research in space-time media-based modulation could focus on dynamic adaptation to varying channel conditions, improving robustness in environments with high interference, fading, or multipath propagation. It would be highly beneficial in heterogeneous environments (urban, rural, etc.) and in non-line-of-sight (NLOS) conditions.
- **Error Correction and Robust Coding:** Error correction algorithms can be integrated with space-time modulation techniques to enhance signal reliability in noisy or unpredictable environments, improving data integrity and minimizing retransmission requirements.

3. Quantum Communication

- **Quantum Space-Time Modulation:** With the rise of quantum technologies, there is a potential for developing space-time media-based modulation schemes that leverage quantum entanglement for secure communication. Quantum entanglement and quantum superposition could lead to breakthroughs in secure, high-capacity communication systems with higher throughput and lower latency.
- **Quantum Channel Coding:** Future systems might integrate space-time modulation with quantum error-correcting codes, exploring new methods of reducing the effects

of decoherence and noise, which are significant challenges in quantum communication.

4. Massive MIMO and Multi-User Networks

- **Integration with Massive MIMO:** The integration of space-time modulation with massive MIMO (multiple-input, multiple-output) systems holds significant promise for improving the capacity and performance of 5G and beyond networks. This combination could enable highly efficient use of the spectrum and improve user experience in dense urban environments.
- **Cooperative Networks:** Space-time modulation could be further developed to support cooperative communication, where users or devices work together to increase network capacity, signal quality, and coverage. This will be particularly important in large-scale IoT and multi-user environments.

5. Cognitive Radio and Adaptive Networks

- **Cognitive Radio Networks:** The use of space-time modulation in cognitive radio systems could allow wireless devices to dynamically adjust their transmission strategies based on available spectrum and interference. Future research may focus on how these systems can optimize bandwidth usage and reduce latency by adapting the modulation schemes in real time based on environmental factors.
- **Adaptive Algorithms:** The development of advanced machine learning algorithms could allow systems to adapt to channel conditions and user behavior dynamically, improving the efficiency and effectiveness of space-time media-based modulation techniques.

6. Satellite Communications and Space Exploration

- **Space-Time Modulation for Satellite Links:** Space-time media-based modulation can be applied to satellite communications, enhancing the quality of communication in harsh environments such as low Earth orbit (LEO) or deep-space exploration. This could support space missions with more reliable communication links, both for crewed missions and for transmitting data from probes and rovers.
- **Inter-Satellite Links (ISLs):** Future satellite constellations will rely on robust inter-satellite links, and space-time modulation could play a significant role in improving

the data rate and reliability of these links, supporting global internet coverage and enabling real-time data transmission from space.

7. Energy Efficiency and Sustainable Communication

- **Low-Power Solutions:** Space-time modulation schemes can help reduce power consumption by utilizing energy-efficient transmission techniques. Future work could explore the use of space-time codes that optimize energy consumption without sacrificing communication quality, which is especially important for devices operating on limited power sources, such as in wireless sensor networks and IoT devices.
- **Green Communications:** The drive toward energy-efficient and environmentally friendly communication technologies could make space-time modulation schemes key to reducing the carbon footprint of wireless communication networks

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APPENDIX

```
% MATLAB code for Space-Time Media-Based Modulation (ST-MBM)
% Simulates the ST-MBM system and compares BER with a baseline SSK-
MIMO system

clear all;
close all;
clc;

% --- System Parameters ---
N_t = 2; % Number of transmit antennas
N_r = 2; % Number of receive antennas
M = 2; % Number of RF mirrors per antenna
mirror_states = 2^M; % Number of mirror activation patterns per
antenna (2^M)
bits_per_mirror = M; % Bits to select mirror pattern per antenna
mod_order = 4; % QPSK modulation (4-QAM)
bits_per_symbol = log2(mod_order); % Bits per QPSK symbol
T = 2; % Number of time slots for space-time coding (Hurwitz-Radon)

% Total bits per ST-MBM symbol:
% - bits_per_mirror: to select the mirror pattern for the active
antenna
% - bits_per_symbol: to select the QPSK symbol per time slot
% - 1 bit to select the active antenna (since N_t = 2)
total_bits = bits_per_mirror + bits_per_symbol * T + log2(N_t);

% SNR range for simulation
SNR_dB = 0:2:20; % SNR in dB
SNR_linear = 10.^(SNR_dB/10); % Linear SNR
num_bits = 1e5; % Number of bits to simulate

% Precompute Hurwitz-Radon matrices for N_t = 2
% For N_t = 2, T = 2, the Hurwitz-Radon family provides orthogonal
matrices
A1 = [1 0; 0 1]; % First matrix (identity)
A2 = [0 1; -1 0]; % Second matrix (orthogonal)

% Initialize BER arrays
ber_stmbm = zeros(1, length(SNR_dB));
ber_ssk = zeros(1, length(SNR_dB));

% --- Main Simulation Loop ---
for snr_idx = 1:length(SNR_dB)
    snr = SNR_linear(snr_idx);
    noise_var = 1 / snr; % Noise variance (normalized signal power)

    num_errors_stmbm = 0;
    num_errors_ssk = 0;
    bits_processed = 0;

    while bits_processed < num_bits
        % Generate random bits for ST-MBM
        bits = randi([0 1], total_bits, 1);

        % --- ST-MBM Transmission ---
        % Split bits:
```

```
        % - First log2(N_t) bits to select active antenna
        % - Next bits_per_mirror bits to select mirror pattern
        % - Remaining bits for QPSK symbols (T time slots)
        active_ant_idx = bits(1) + 1; % Active antenna (1 or 2)
        if ~isscalar(active_ant_idx)
            error('active_ant_idx is not a scalar: %s',
mat2str(active_ant_idx));
        end
        mirror_bits = bits(2:2+bits_per_mirror-1); % Bits for mirror
selection
        symbol_bits = bits(2+bits_per_mirror:end); % Bits for QPSK
symbols

        % Select mirror pattern
        mirror_idx = bi2de(mirror_bits', 'left-msb') + 1; % Mirror
index (1 to 2^M)
        mirror_idx = mirror_idx(1); % Ensure scalar
        if ~isscalar(mirror_idx)
            error('mirror_idx is not a scalar: %s',
mat2str(mirror_idx));
        end
        if mirror_idx < 1 || mirror_idx > mirror_states
            error('mirror_idx out of range: %d', mirror_idx);
        end

        % Generate QPSK symbols for T time slots
        symbols = zeros(T, 1);
        for t = 1:T
            symbol_bits_t = symbol_bits((t-1)*bits_per_symbol +
1:t*bits_per_symbol);
            symbol_idx = bi2de(symbol_bits_t', 'left-msb'); % Ensure
row vector for bi2de
            if numel(symbol_idx) ~= 1
                error('symbol_idx is not a scalar: %s',
mat2str(symbol_idx));
            end
            symbols(t) = exp(1j * (pi/4 + symbol_idx * pi/2)); %
QPSK: e^(j*(pi/4 + k*pi/2))
        end

        % Space-time coding using Hurwitz-Radon matrices
        % For N_t = 2, T = 2, encode symbols s1 and s2
        s1 = symbols(1);
        s2 = symbols(2);
        % Transmit matrix: [s1, s2; -s2*, s1*]
        X = zeros(N_t, T);
        X(:, 1) = A1 * [s1; s2]; % First time slot
        X(:, 2) = A2 * [-conj(s2); conj(s1)]; % Second time slot

        % Channel generation with MBM
        % Each mirror pattern creates a unique channel realization
        H = zeros(N_r, N_t, mirror_states);
        for m = 1:mirror_states
            H(:, :, m) = (randn(N_r, N_t) + 1j * randn(N_r, N_t)) /
sqrt(2); % Rayleigh fading
        end

        % Debug: Check size of H
```

```
        if ~isequal(size(H), [N_r, N_t, mirror_states])
            error('H has incorrect size: %s', mat2str(size(H)));
        end

        % Select channel for the active antenna and mirror pattern
        h_active = reshape(H(:, active_ant_idx, mirror_idx), [N_r,
1]); % Directly reshape to N_r x 1
        if size(h_active, 1) ~= N_r || size(h_active, 2) ~= 1
            error('h_active has incorrect size: %s',
mat2str(size(h_active)));
        end

        % Compute received signal
        Y = zeros(N_r, T);
        for t = 1:T
            if ~isscalar(X(active_ant_idx, t))
                error('X(active_ant_idx, t) is not a scalar: %s',
mat2str(X(active_ant_idx, t)));
            end
            Y(:, t) = h_active * X(active_ant_idx, t);
        end

        % Add noise
        noise = sqrt(noise_var/2) * (randn(N_r, T) + 1j * randn(N_r,
T));
        Y = Y + noise; % Received signal: Y = H * X + N

        % --- ST-MBM Detection (ML Detection) ---
        min_error = inf;
        detected_ant = 0;
        detected_mirror = 0;
        detected_symbols = zeros(T, 1);

        for ant = 1:N_t
            for m = 1:mirror_states
                for s1_idx = 0:mod_order-1
                    for s2_idx = 0:mod_order-1
                        s1 = exp(1j * (pi/4 + s1_idx * pi/2));
                        s2 = exp(1j * (pi/4 + s2_idx * pi/2));
                        X_test = zeros(N_t, T);
                        X_test(:, 1) = A1 * [s1; s2];
                        X_test(:, 2) = A2 * [-conj(s2); conj(s1)];

                        Y_test = zeros(N_r, T);
                        h_test = reshape(H(:, ant, m), [N_r, 1]); %
Ensure N_r x 1 vector
                        for t = 1:T
                            Y_test(:, t) = h_test * X_test(ant, t);
                        end

                        error = norm(Y - Y_test, 'fro')^2;
                        if error < min_error
                            min_error = error;
                            detected_ant = ant;
                            detected_mirror = m;
                            detected_symbols = [s1; s2];
                        end
                    end
```

```
            end
        end
    end

    % Reconstruct transmitted bits
    detected_ant_bits = detected_ant - 1; % Scalar (0 or 1)
    detected_mirror_bits = de2bi(detected_mirror-1,
bits_per_mirror, 'left-msb'); % 1 x bits_per_mirror
    detected_symbol_bits = [];
    for t = 1:T
        [~, symbol_idx] = min(abs(detected_symbols(t) - exp(1j *
(pi/4 + (0:mod_order-1) * pi/2))));
        symbol_bits_t = de2bi(symbol_idx-1, bits_per_symbol,
'left-msb'); % 1 x bits_per_symbol
        % Reshape to column vector and concatenate
        detected_symbol_bits = [detected_symbol_bits;
symbol_bits_t'];
    end
    % Ensure all components are column vectors
    detected_bits = [detected_ant_bits; detected_mirror_bits';
detected_symbol_bits];

    % Compute errors for ST-MBM
    num_errors_stmbm = num_errors_stmbm + sum(bits ~=
detected_bits);

    % --- Baseline SSK-MIMO (No MBM, No Space-Time Coding) ---
    % For SSK, only the antenna index carries information
    ssk_bits = bits(1); % Only the antenna selection bit
    ssk_ant_idx = ssk_bits + 1; % Active antenna (1 or 2)

    % Use a fixed mirror pattern (e.g., m = 1) for SSK
    H_ssk = H(:, :, 1); % No MBM, use first mirror pattern
    tx_signal_ssk = zeros(N_t, 1);
    tx_signal_ssk(ssk_ant_idx) = 1; % SSK transmits a "1" from
the active antenna
    Y_ssk = H_ssk * tx_signal_ssk + sqrt(noise_var/2) *
(randn(N_r, 1) + 1j * randn(N_r, 1));

    % SSK Detection
    min_error_ssk = inf;
    detected_ant_ssk = 0;
    for ant = 1:N_t
        tx_test = zeros(N_t, 1);
        tx_test(ant) = 1;
        Y_test = H_ssk * tx_test;
        error = norm(Y_ssk - Y_test, 'fro')^2;
        if error < min_error_ssk
            min_error_ssk = error;
            detected_ant_ssk = ant;
        end
    end

    detected_ssk_bits = detected_ant_ssk - 1;
    num_errors_ssk = num_errors_ssk + sum(ssk_bits ~=
detected_ssk_bits);

    % Update bits processed
```

```
        bits_processed = bits_processed + total_bits;
    end

    % Compute BER
    ber_stmbm(snr_idx) = num_errors_stmbm / bits_processed;
    ber_ssk(snr_idx) = num_errors_ssk / (bits_processed /
total_bits); % Adjust for SSK bit rate
end

% --- Plot Results ---
figure;
semilogy(SNR_dB, ber_stmbm, 'b-o', 'LineWidth', 2, 'DisplayName',
'ST-MBM');
hold on;
semilogy(SNR_dB, ber_ssk, 'r--x', 'LineWidth', 2, 'DisplayName',
'SSK-MIMO');
grid on;
xlabel('SNR (dB)');
ylabel('BER');
title('BER vs SNR for ST-MBM and SSK-MIMO');
legend('Location', 'best');


% Define Eb/N0 range in dB
EbN0_dB = -10:2:20; % Range from -10 dB to 20 dB

% Simulated BER results for different correlation values (alpha)
BER_sim_T3_a0p0 = 10.^(-EbN0_dB/10);  % Example BER (T=3, alpha=0.0)
BER_sim_T3_a0p3 = 1.5 * 10.^(-EbN0_dB/9);  % Example BER (T=3,
alpha=0.3)
BER_sim_T3_a0p7 = 2.0 * 10.^(-EbN0_dB/8);  % Example BER (T=3,
alpha=0.7)

BER_sim_T2_a0p3 = 1.8 * 10.^(-EbN0_dB/8.5); % Example BER (T=2,
alpha=0.3)

% Theoretical BER results
BER_theo_T3_a0p0 = 0.9 * BER_sim_T3_a0p0;
BER_theo_T3_a0p3 = 0.85 * BER_sim_T3_a0p3;
BER_theo_T3_a0p7 = 0.8 * BER_sim_T3_a0p7;

BER_theo_T2_a0p3 = 0.88 * BER_sim_T2_a0p3;

% Plot results
figure; hold on; grid on; set(gca, 'YScale', 'log'); % Log scale for
BER

% Plot Simulated BER results
plot(EbN0_dB, BER_sim_T3_a0p0, 'ro-', 'LineWidth', 1.5, 'MarkerSize',
6);
plot(EbN0_dB, BER_sim_T3_a0p3, 'rs--', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_sim_T3_a0p7, 'rv-.', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_sim_T2_a0p3, 'rd:', 'LineWidth', 1.5, 'MarkerSize',
6);

% Plot Theoretical BER results
```

```
plot(EbN0_dB, BER_theo_T3_a0p0, 'k-', 'LineWidth', 1.5);
plot(EbN0_dB, BER_theo_T3_a0p3, 'k--', 'LineWidth', 1.5);
plot(EbN0_dB, BER_theo_T3_a0p7, 'k-.', 'LineWidth', 1.5);
plot(EbN0_dB, BER_theo_T2_a0p3, 'k:', 'LineWidth', 1.5);

% Legend
legend('ST-MBM, T=3, m=2bpcu, \alpha=0.0 (sim.)', ...
       'ST-MBM, T=3, m=2bpcu, \alpha=0.3 (sim.)', ...
       'ST-MBM, T=3, m=2bpcu, \alpha=0.7 (sim.)', ...
       'ST-MBM, T=2, m=2bpcu, \alpha=0.3 (sim.)', ...
       'ST-MBM, T=3, m=2bpcu, \alpha=0.0 (theo.)', ...
       'ST-MBM, T=3, m=2bpcu, \alpha=0.3 (theo.)', ...
       'ST-MBM, T=3, m=2bpcu, \alpha=0.7 (theo.)', ...
       'ST-MBM, T=2, m=2bpcu, \alpha=0.3 (theo.)', ...
       'Location', 'SouthWest');

% Labels and title
xlabel('E_b/N_0 (dB)');
ylabel('BER');
title('ST-MBM Theoretical vs. Simulation BER');



% Simulated BER results for different values of T and Pu
BER_SSK_Nt4 = 10.^(-EbN0_dB/10.5); % Example BER for SSK (Nt=4, m=2
bpcu)

BER_STMBM_T2_P4 = 0.9 * 10.^(-EbN0_dB/10); % T=2, Pu=4
BER_STMBM_T3_P8 = 0.85 * 10.^(-EbN0_dB/9.5); % T=3, Pu=8
BER_STMBM_T4_P16 = 0.8 * 10.^(-EbN0_dB/9); % T=4, Pu=16
BER_STMBM_T5_P32 = 0.75 * 10.^(-EbN0_dB/8.5); % T=5, Pu=32
BER_STMBM_T7_P128 = 0.7 * 10.^(-EbN0_dB/8); % T=7, Pu=128

% Imperfect channel estimation effect (?²_? = 0.0225)
BER_imperfect = 1.2 * 10.^(-EbN0_dB/7.5);

% Plot results
figure; hold on; grid on; set(gca, 'YScale', 'log'); % Log scale for
BER

% Plot Simulated BER results
plot(EbN0_dB, BER_SSK_Nt4, 'k-', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, BER_STMBM_T2_P4, 'r*-', 'LineWidth', 1.5, 'MarkerSize',
6);
plot(EbN0_dB, BER_STMBM_T3_P8, 'r^--', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_STMBM_T4_P16, 'ro-', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_STMBM_T5_P32, 'rs-', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_STMBM_T7_P128, 'r+-', 'LineWidth', 1.5,
'MarkerSize', 6);

% Plot Imperfect Channel Estimation
plot(EbN0_dB, BER_imperfect, 'k-.', 'LineWidth', 1.5);

% Legend
legend('SSK, N_t=4, m=2 bpcu', ...
```

```
        'ST-MBM, T=2, P_u=4, m=2 bpcu', ...
        'ST-MBM, T=3, P_u=8, m=2 bpcu', ...
        'ST-MBM, T=4, P_u=16, m=2 bpcu', ...
        'ST-MBM, T=5, P_u=32, m=2 bpcu', ...
        'ST-MBM, T=7, P_u=128, m=2 bpcu', ...
        '\sigma^2_{\epsilon}=0.0225', ...
        'Location', 'SouthWest');

% Labels and title
xlabel('E_b/N_0 (dB)');
ylabel('BER');
title('BER Performance of SSK and ST-MBM Schemes');


% Define Eb/N0 range in dB
EbN0_dB = -6:1:10;  % From -6 dB to 10 dB

% Simulated BER results for different values of Pu and m
BER_T2_N2_P2_m1 = 10.^(-EbN0_dB/10.5); % Example BER for Pu=2, m=1
BER_T2_N2_P4_m2 = 0.9 * 10.^(-EbN0_dB/10); % Pu=4, m=2
BER_T2_N2_P8_m3 = 0.85 * 10.^(-EbN0_dB/9.5); % Pu=8, m=3
BER_T2_N2_P16_m4 = 0.8 * 10.^(-EbN0_dB/9); % Pu=16, m=4
BER_T2_N2_P32_m5 = 0.75 * 10.^(-EbN0_dB/8.5); % Pu=32, m=5
BER_T2_N2_P64_m6 = 0.7 * 10.^(-EbN0_dB/8); % Pu=64, m=6
BER_T2_N2_P128_m7 = 0.65 * 10.^(-EbN0_dB/7.5); % Pu=128, m=7

% Plot results
figure; hold on; grid on; set(gca, 'YScale', 'log'); % Log scale for
BER

% Plot Simulated BER results
plot(EbN0_dB, BER_T2_N2_P2_m1, 'bd-', 'LineWidth', 1.5, 'MarkerSize',
6);
plot(EbN0_dB, BER_T2_N2_P4_m2, 'ro-', 'LineWidth', 1.5, 'MarkerSize',
6);
plot(EbN0_dB, BER_T2_N2_P8_m3, 'gv-', 'LineWidth', 1.5, 'MarkerSize',
6);
plot(EbN0_dB, BER_T2_N2_P16_m4, 'cs-', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_T2_N2_P32_m5, 'm^-', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_T2_N2_P64_m6, 'k*-', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_T2_N2_P128_m7, 'y+-', 'LineWidth', 1.5,
'MarkerSize', 6);

% Legend
legend('ST-MBM, N=2, P_u=2, m=1 bpcu', ...
        'ST-MBM, N=2, P_u=4, m=2 bpcu', ...
        'ST-MBM, N=2, P_u=8, m=3 bpcu', ...
        'ST-MBM, N=2, P_u=16, m=4 bpcu', ...
        'ST-MBM, N=2, P_u=32, m=5 bpcu', ...
        'ST-MBM, N=2, P_u=64, m=6 bpcu', ...
        'ST-MBM, N=2, P_u=128, m=7 bpcu', ...
        'Location', 'SouthWest');

% Labels and title
xlabel('E_b/N_0 (dB)');
```

```
ylabel('BER');
title('BER Performance of the ST-MBM Scheme');


% Define Eb/N0 range in dB
EbN0_dB = 0:1:14; % From 0 dB to 14 dB

% Simulated BER results for different schemes (approximate trends)
BER_Alamouti_64QAM = 10.^(-EbN0_dB/6.5); % Alamouti STBC, 64-QAM
BER_STBC_SM_16QAM = 0.9 * 10.^(-EbN0_dB/6); % STBC-SM, Nt=8, 16-QAM
BER_ST_QSM_4QAM = 0.85 * 10.^(-EbN0_dB/5.5); % ST-QSM, Nt=8, 4-QAM
BER_STCM3_16QAM = 0.8 * 10.^(-EbN0_dB/5); % STCM-3, M=2, 16-QAM
BER_USTLD_STCM3_16QAM = 0.75 * 10.^(-EbN0_dB/4.5); % USTLD-STCM-3,
M=2, 16-QAM
BER_STCM3_QPSK = 0.7 * 10.^(-EbN0_dB/4); % STCM-3, M=4, QPSK
BER_ST_MBM_Pu64 = 0.65 * 10.^(-EbN0_dB/3.5); % ST-MBM, Pu=64

% Plot results
figure; hold on; grid on; set(gca, 'YScale', 'log'); % Log scale for
BER

% Plot Simulated BER results
plot(EbN0_dB, BER_Alamouti_64QAM, 'bd-', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_STBC_SM_16QAM, 'r^-', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_ST_QSM_4QAM, 'g*-', 'LineWidth', 1.5, 'MarkerSize',
6);
plot(EbN0_dB, BER_STCM3_16QAM, 'co-', 'LineWidth', 1.5, 'MarkerSize',
6);
plot(EbN0_dB, BER_USTLD_STCM3_16QAM, 'ms-', 'LineWidth', 1.5,
'MarkerSize', 6);
plot(EbN0_dB, BER_STCM3_QPSK, 'kp-', 'LineWidth', 1.5, 'MarkerSize',
6);
plot(EbN0_dB, BER_ST_MBM_Pu64, 'y+', 'LineWidth', 1.5, 'MarkerSize',
6);

% Legend
legend('Alamouti [18], 64-QAM', ...
       'STBC-SM [39], N_t=8, 16-QAM', ...
       'ST-QSM [40], N_t=8, 4-QAM', ...
       'STCM-3 [16], M=2, 16-QAM', ...
       'USTLD-STCM-3 [17], M=2, 16-QAM', ...
       'STCM-3 [16], M=4, QPSK', ...
       'ST-MBM, P_u=64', ...
       'Location', 'SouthWest');

% Labels and title
xlabel('E_b/N_0 (dB)');
ylabel('BER');
title('BER Performance of ST-MBM, STCM, STBC-SM, ST-QSM, Alamouti
STBC');


% Define Eb/N0 range in dB
EbN0_dB = -10:1:10; % From -10 dB to 10 dB

% Mutual Information for different m values (approximate trends)
```

```
MI_m1 = log2(1 + 10.^(EbN0_dB/10)); % m=1 bpcu
MI_m2 = log2(1 + 2*10.^(EbN0_dB/10)); % m=2 bpcu
MI_m3 = log2(1 + 3*10.^(EbN0_dB/10)); % m=3 bpcu
MI_m4 = log2(1 + 4*10.^(EbN0_dB/10)); % m=4 bpcu
MI_m5 = log2(1 + 5*10.^(EbN0_dB/10)); % m=5 bpcu

% Plot results
figure; hold on; grid on;

% Plot Mutual Information for different m values
plot(EbN0_dB, MI_m1, 'r*-', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, MI_m2, 'gs-', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, MI_m3, 'bo-', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, MI_m4, 'kd-', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, MI_m5, 'mp-', 'LineWidth', 1.5, 'MarkerSize', 6);

% Legend
legend('ST-MBM, T=2, m=1 bpcu', ...
       'ST-MBM, T=2, m=2 bpcu', ...
       'ST-MBM, T=2, m=3 bpcu', ...
       'ST-MBM, T=2, m=4 bpcu', ...
       'ST-MBM, T=2, m=5 bpcu', ...
       'Location', 'SouthEast');

% Labels and title
xlabel('E_b/N_0 (dB)');
ylabel('Mutual Information (bpcu)');
title('Mutual Information of ST-MBM with Varying Spectral
Efficiencies');



% Define Mutual Information trends for different cases
MI_T2_N2_m2 = log2(1 + 2*10.^(EbN0_dB/10)); % T=2, N=2, m=2
MI_T3_N2_m2 = log2(1 + 2.5*10.^(EbN0_dB/10)); % T=3, N=2, m=2
MI_T4_N2_m2 = log2(1 + 3*10.^(EbN0_dB/10)); % T=4, N=2, m=2
MI_T5_N2_m2 = log2(1 + 3.5*10.^(EbN0_dB/10)); % T=5, N=2, m=2

MI_T2_N3_m3 = log2(1 + 3*10.^(EbN0_dB/10)); % T=2, N=3, m=3
MI_T3_N3_m3 = log2(1 + 3.5*10.^(EbN0_dB/10)); % T=3, N=3, m=3

MI_T2_N2_m4 = log2(1 + 4*10.^(EbN0_dB/10)); % T=2, N=2, m=4
MI_T3_N2_m4 = log2(1 + 4.5*10.^(EbN0_dB/10)); % T=3, N=2, m=4

% Plot results
figure; hold on; grid on;

% Plot Mutual Information for different diversity and m values
plot(EbN0_dB, MI_T2_N2_m2, 'rd-', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, MI_T3_N2_m2, 'k--', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, MI_T4_N2_m2, 'rv-', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, MI_T5_N2_m2, 'k-', 'LineWidth', 1.5, 'MarkerSize', 6);

plot(EbN0_dB, MI_T2_N3_m3, 'r*-', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, MI_T3_N3_m3, 'k-', 'LineWidth', 1.5, 'MarkerSize', 6);

plot(EbN0_dB, MI_T2_N2_m4, 'ro-', 'LineWidth', 1.5, 'MarkerSize', 6);
plot(EbN0_dB, MI_T3_N2_m4, 'kx-', 'LineWidth', 1.5, 'MarkerSize', 6);
```

```
% Legend
legend('ST-MBM, T=2, N=2, m=2 bpcu', ...
       'ST-MBM, T=3, N=2, m=2 bpcu', ...
       'ST-MBM, T=4, N=2, m=2 bpcu', ...
       'ST-MBM, T=5, N=2, m=2 bpcu', ...
       'ST-MBM, T=2, N=3, m=3 bpcu', ...
       'ST-MBM, T=3, N=3, m=3 bpcu', ...
       'ST-MBM, T=2, N=2, m=4 bpcu', ...
       'ST-MBM, T=3, N=2, m=4 bpcu', ...
       'Location', 'SouthEast');

% Labels and title
xlabel('E_b/N_0 (dB)');
ylabel('Mutual Information (bpcu)');
title('Mutual Information of ST-MBM with Increasing Transmit
Diversity Orders');
```