Validating wireless system Design via **MATLAB** Simulations

EWCN Laboratory
Session 1

Department of Electronics and Communication Engineering
Indian Institute of Information Technology Allahabad

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Outline

- MATLAB Introduction
- Fundamentals: Data Types, Arithmetic Operations
- Arrays and Matrices
- Scripts and Functions
- Conditional Statements and Loops
- Monte Carlo Simulation
- Examples on Wireless System Design

Introduction

- Stands for MATRIX Laboratory.
  1. Highly optimized for matrix operations.
  2. Basic element is array that does not require dimensioning.
- Highly interactive, interpreted programming language.
- High-level language for technical computing with great visualization capabilities.
- MATLAB in default view has four smaller windows:
  1. Command Window.
  2. Current folder Window.
  3. Workspace Window.
  4. Command History Window.
- Besides the above windows there are: Editor Window, Help Window, Figure Window.

Language Features: Data types

- Numeric Arrays
  1. Numeric data types may be of single, double, int8, int16, int32, int64, uint8, uint16, uint32, uint64, NaN, Inf.
  2. One based indexing and Column wise data access.
- Cell and Cell Arrays:
  1. Collection of data of any MATLAB type. Constructed with {} or cell.
  2. c={14, [1, 2 ;5, 10], 'Hello'}
  3. Storage efficiency is poor.
- Struct and Struct Arrays
  1. Like cell arrays, can hold arbitrary MATLAB data types. However, each entry is associated with a field. Structures can be arranged in N-D arrays: structure arrays
  2. classes = struct('name', {'a1', 'a2'}, 'units', {1,2}, 'grade', {'P', 'P'})
  3. >> classes(2) gives the output :
     name: 'a2'
     units: 2
     grade: 'P'
- Function Handles (@): Callable association to MATLAB function stored in variable

Arithmetic Operations & Variable Naming

- Semicolon is used to suppress command output.
- clc command clears the command window.
- Arithmetic operations possible:Addition, Subtraction, Multiplication, Right division (/) , Left division (\) and Exponentiation ($\wedge$).
- MATLAB operations on numeric arrays are matrix operations.
- Prepend "." for element-wise operations.
- Rules about Variable names
  1. Must begin with a letter.
  2. Maximum 63 characters. No space allowed.
  3. Can have letters, digits, and underscore characters.
- Case sensitive.

Arrays and Matrices in MATLAB

- Creation of One dimensional Array:
  1. *var_name=[elements]*.
  2. For row vector separate the elements with comma or space and for column vector use semicolon or press enter after each element.
  3. *var_name=[m:q:n] or m: q: n*.
  4. *var_name=linspace(initial, final, n)*.
- Creation of Matrices:
  1. *var_name=[first row elements; second row elements ;.....; last row]*
- Accessing element
  1. For Vector: *var_name[element indices]*
  2. For Matrix: *var_name[row, column]*
- Special Commands: zeros(m,n), ones(m,n), eye(n).
- Two vectors (matrices) are appended horizontally and vertically by using [A, B] and [A; B], respectively.

Scripts and Functions

- Scripts
  1. Execute a series of MATLAB statements.
  2. Uses base workspace.
- Functions
  1. Accept inputs, execute a series of MATLAB statements, and return outputs.
  2. Functions will not manipulate variable(s)/matrices(s) in the Matlab Workspace.
  3. Matlab functions have the **function** keyword.
  4. Function Definition: *function[output argu.]=function_name(input argu.)*
     1. Rules of the function naming are same as for a variable.
     2. input and output arguments are separated by comma.
     3. Function file is recommended to be identical to the function name.
  5. Function Body: Contains the computer program.

Functions

- Function for the given implementation is

$$\int_a^b f(x)dx = \sum_{i=1}^{n} \left(\frac{b-a}{n}\right)\left[f(x_{i+\frac{1}{2}} + f(x_{i-\frac{1}{2}})\right] \tag{1}$$

- Function code:

```
function fout = traprule(f, a, b, n)
x=linspace(a,b,nel+1)'
int f=0.5*((b-a)/n)*sum(f(x(1: end-1))+f(x(2: end)));
```

Anonymous Functions

- Functions without a file.
  1. Stored directly in function handle (@).
  2. Store expression and required variables.
- Array of function handle not allowed; function handle may return array.
- Example: f1= @(x, y)[sin($\pi * x$), cos($\pi * y$), tan($\pi * x * y$)]
- f1(0.12, 0.56) will return the output value of f1.

Conditionals Statements

- To perform conditional operations we have **if-end**, **if-else-end**, **if-elseif-else-end** Structures along with the **switch-case** statements.
- Syntax:

```
if condition
    commands
else
    commands
end
```

- Syntax for Switch :

```
switch switch expression
    case value1
        commands
    case value2
        commands
    otherwise
        commands
end
```

Loops in MATLAB

- We have **for** and **while**.
- Syntax for for loop:

```
for k= initial: increment: final
    Statement1
    Statement2
end
```

- Syntax for while loop:

```
while conditional expression
    Statement1
    Statement2
end
```

Validating Wireless System Design via MATLAB

- Wireless system design can be validated using Monte-Carlo Simulations in MATLAB.
- Monte Carlo Simulation
  1. A statistical technique used to model probabilistic (or "stochastic") systems and establish the odds for a variety of outcomes.
  2. Monte Carlo simulation uses essentially random inputs (within realistic limits) to model the system and produce probable outcomes.
  3. Deterministic simulations: Produces same result for every run.
  4. Stochastic simulations: Answer will differ from run to run, because there's an element of randomness in it.

Validating Wireless System Design: Approach

1. Define a Wireless System under some realistic constraints/assumptions.
2. Evaluate the System Performance by obtaining the closed-form expressions.
3. These expressions involve various parameters on which the system design depends and help us to analyze the effect of these on the system performance.
4. The above task was the Theoretical analysis.
5. Simulations provide an approximate how the system behaves in real time.
6. We validate the above theoretical analysis with the Simulations.

Wireless Communications: Preliminaries

Over the wireless channel, the transmitted signal is impaired by three effects:

1. Pathloss: Averaging the received power at a particular distance over a sufficiently large area, yields the loss in power. The pathloss law is deterministic.
2. Shadowing: Averaging the received power at a particular distance over an area of approximately shadowing coherence distance yields a variation in the received power around the pathloss. This variation is shadowing and is random in nature.
3. Fading: If we donot average the signal at all allows one to observe fading as a signal fluctuation around pathloss and shadowing. It is random and caused due to multipath propagation.

Wireless Communications: Preliminaries

1. Diversity gains: Providing additional independent copies of the same information via independent shadowing and fading channels yields diversity gains.
2. Channel Modelling:
   - Rician Fading: If a strong Line-of-sight (LOS) is present, the envelope of the channel amplitude follows Ricean distribution.

$$f(x) = \frac{x}{\Omega} e^{-\frac{x^2}{2\Omega}}, x > 0 \tag{2}$$

   - Rayleigh Fading: If all the multipath components are equally random, then the envelope follows Rayleigh fading.
   - Nakagami-m: If some of the contributions are phase aligned we have a Nakagami-m fading.

Case 1: A Basic Wireless Communication System

Consider a system where a source node S communicates with a destination node D over a wireless channel as shown below.

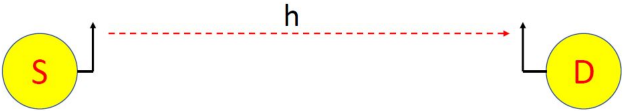

Figure: Considered System Model

Case 1 Continued......

Assumptions

1. Nodes are equipped with a single antenna and operate in half-duplex mode. AWGN noise is assumed at the receiver.
2. We assume that the channel coefficient h for the link $S \rightarrow D$ experiences Rayleigh flat fading.
3. Since the channel coefficients are Rayleigh distributed, the channel gain $|h_{SD}|^2$ will be exponentially distributed with the CDF and PDF given by

$$F_{|h_{SD}|^2}(x) = 1 - \mathrm{e}^{-\frac{x}{\Omega_{SD}}}. \tag{3}$$

$$f_{|h_{SD}|^2}(x) = \frac{1}{\Omega_{SD}}\mathrm{e}^{-\frac{x}{\Omega_{SD}}}. \tag{4}$$

Case 1 Continued......

Analysis

1. Received instantaneous Signal-to-Noise ratio (SNR) at the receiver given by $\Lambda_D = \rho|h_{SD}|^2$, where $\rho = \frac{P_S}{N_0}$ is the transmit SNR.
2. Outage Probability is given by

$$P_{out} = \Pr\left[C_{SD} < R\right], \tag{5}$$

where $C_{SD} = \log_2(1 + \Lambda_D)$ is the instantaneous capacity for the link $S \rightarrow D$ and R is the threshold rate. Further, (5) can be re-expressed as

$$P_{out} = \Pr\left[|h_{SD}|^2 < \frac{\eta}{\rho}\right] \tag{6}$$

$$= 1 - e^{-\frac{\eta}{\rho\Omega_{SD}}} \tag{7}$$

$$= F_{|h_{SD}|^2}\left(\frac{\eta}{\rho}\right) \tag{8}$$

Case 1 Continued......

- Theoretically, system outage performance is given by (8).
- Next Step is to simulate the above environment in MATLAB and observe the outage performance.
- Follow the following steps
  1. Generate an exponentially distributed random variable ($|h_{SD}|^2$) of a given mean value.
  2. Obtain the Instantaneous SNR.
  3. Check if $C_{SD} < R$, then counter $c \rightarrow c + 1$.
  4. Repeat Steps 1, 2, and 3 for a given number of trails for a ρ.
  5. For a given ρ, after finishing up with the trials we have $P_{out} = \frac{\text{c}}{\text{number of trials}}$
  6. Repeat the above steps 1-5 to obtain the outage values for different ρ.
- Now check whether the theoretical results are matching with the simulation results to verify the theoretical analysis.

Case 1 Results......

- Assume $\Omega_{SD} = 4, R = 0.5$ bps/Hz
- Theoretical outage results for $\rho = 0 : 3 : 30$ is given below
- [0.0983721, 0.0505759, 0.0256761, 0.012952, 0.00651248, 0.00326929, 0.00163986, 0.000822216, 0.000412169, 0.000206595, 0.000103548]
- Simulated outage results (10^5 trials) for $\rho = 0 : 3 : 30$ is given below
- [0.0984 0.0506 0.0257 0.0130 0.0065 0.0033 0.0016 0.0008 0.0004 0.0002 0.0001]

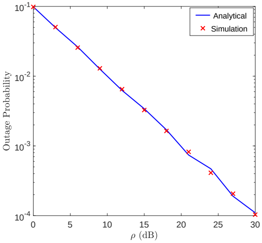

Figure: Outage probability versus ρ

Experiment 1.1

1. Consider a scenario, where a source node S communicates with a destination node D over the wireless channel. With single antenna and half duplex operation under the Rayleigh fading, plot the Ergodic capacity versus the transmit SNR plot.

Experiment 1.2

1. Consider a scenario, where N number of source node $S_\imath$ are there which communicate with a destination node D over the wireless channel.. Amongst these source nodes, the node with best channel to the destination is selected at a time to communicate. With single antenna and half duplex operation under the Rayleigh fading, plot the system outage performance versus the transmit SNR plot. Also, plot the ergodic capacity versus SNR plot. Assume $N > 3$ for analysis. What is the diversity achieved here?

Experiment 1.3

1. Consider a scenario, where a source node S with a single antenna communicates with a destination node D with L antennas over the wireless channel. At D, the contributions at all the antenna terminals are added. With half duplex operation under the Rayleigh fading, plot the system outage performance versus the transmit SNR plot. Also, plot the ergodic capacity versus SNR plot. Assume $L > 3$ for analysis. What is the diversity achieved here?