# Project Based Learning Report For B. Tech Sem – VI

**Department of**

# Electronics & Communication Engineering

## Bharati Vidyapeeth (Deemed to be University) College of Engineering, Pune – 411043

**Academic Year: 2023-24**

**Project Based Learning Report**

**On,**

**Title of the topic:**

**LTE Waveform Modeling Using Downlink Transport and Physical Channels using LTE Toolbox in Matlab**

Submitted in the partial fulfillment of the requirements For the Project based learning in,

( **Cellular technology and 4G** )

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By

**PRN Name of student**

**2114110475 Naveen Kumar**

**2114110472 Praveen Kumar**

Under the guidance of Course In-charge Prof. Dr. Tanuja.S Dhope

Department of

Electronics & Communication Engineering

Bharati Vidyapeeth (Deemed to be University) College of Engineering,

Pune – 411043

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**Bharati Vidyapeeth (Deemed to be University) College of Engineering, Pune – 411043**

**DEPARTMENT OF**

**ELECTRONICS & COMMUNICATION ENGINEERING**

**CERTIFICATE**

Certified that the Project Based Learning report entitled, “LTE Waveform Modeling Using Downlink Transport and Physical Channels using LTE Toolbox in Matlab.**”** is work done by,

**PRN NAME OF STUDENT**

**2114110475 NAVEEN KUMAR**

**2114110472 PRAVEEN KUMAR**

in partial fulfillment of the requirements for the award of credits for Project Based Learning (PBL) in **Cellular technology and 4G** of Bachelor of Technology Semester VI, in Electronics and Communication Engineering.

**Date : 20/3/2024**

**Prof. Dr. Tanuja.S Dhope Dr. Arundhati A. Shinde**

**Course In-charge Head of department**

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**CHAPTER – 1**

**PROBLEM STATEMENT**

Engineers miss out on advanced simulations and analysis capabilities without LTE toolbox. They won’t be able to configure, simulate, measure, and analyze end-to-end communications links effectively. LTE technology is complex, and managing it requires skilled personnel. Organizations need experts who understand the intricacies of LTE systems. In summary, not using the LTE Toolbox may lead to missed opportunities for advanced simulations, signal coverage limitations, and compatibility issues with older devices. Engineers and organizations should carefully consider these drawbacks when deciding whether to utilize the LTE Toolbox for their projects.

**SOLUTION**

Requirement of LTE toolbox:

LTE Toolbox provides standard-compliant functions and apps for the design, simulation, and verification of LTE, LTE-Advanced, and LTE-Advanced Pro communications systems. The toolbox accelerates LTE algorithm and physical layer (PHY) development, supports golden reference verification and conformance testing, and enables test waveform generation.

With the toolbox you can configure, simulate, measure, and analyze end-to-end communications links. You can also create and reuse a conformance test bench to verify that your designs, prototypes, and implementations comply with the LTE standard.

Using LTE Toolbox with RF instruments or hardware support packages, you can connect transmitter and receiver models to radio devices and verify your designs via over-the-air transmission and reception.

To develop an LTE Waveform Modeling Using Downlink Transport and Physical Channels using LTE Toolbox in Matlab

To generate a time-domain waveform that includes several key components of the downlink transmission in an LTE (Long-Term Evolution) system. Specifically, we’ll focus on the Physical Downlink Shared Channel (PDSCH), the corresponding Physical Downlink Control Channel (PDCCH) transmission, and the Physical Control Format Indicator Channel (PCFICH) for one subframe.

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**CHAPTER – 2**

**INTRODUCTION**

The introduction of LTE-M to the LTE standard added support specifically aimed at Machine-Type Communications (MTC). Starting with Cat-0 devices in Release 12, this was further extended in later releases to define a separate Cat-M class of devices. Two categories have now been added to LTE, Cat-M1 in Release 13 (through the eMTC work items) followed by Cat-M2 in Release 14 ( feMTC).

There are two coverage enhancement (CE) modes of operation for Cat-M devices (also referred to as BL/CE UEs in 3GPP standard documents), CE mode A and CE mode B. The CE mode A targets modest coverage enhancement with up to 32 repetitions whereas CE mode B targets extensive coverage enhancement with up to 2048 repetitions for the data channel. CE mode A is signaled via DCI format 6-0A/6-1A messages and CE mode B via 6-0B/6-1B messages.

The MPDCCH processing chain, DM-RS creation and mapping is almost identical to that of the Enhanced Physical Downlink Control Channel (EPDCCH), plus the addition of repetitions and frequency hopping behavior. This example makes specific use of LTE Toolbox EPDCCH functionality to implement the MPDCCH model. The LTE-M data channel is the LTE PDSCH with addition of repetitions and frequency hopping. The LTE-M broadcast channel consists of two parts; the 'core' part corresponding to the LTE PBCH and the LTE-M specific 'repetition' part where the symbols and cell RS signals in the 'core' part are repeated.

LTE-M can be deployed in standard LTE cells, therefore not all subframes are necessarily used for BL/CE transmission. The BL/CE subframes are indicated by a bitmap sent in the MIB-M message (similar to the mechanism in NB-IoT). For simplicity, in this example, we assume that all subframes are defined to be BL/CE. The MPDCCH/PDSCH starting OFDM symbol for LTE-M transmissions are cell-specific and is broadcasted in the System Information (SI).

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The main output of this MATLAB example is a multi-subframe Cat-M1/Cat-M2 resource grid containing the MPDCCH Resource Elements (RE), associated DM-RS, the LTE-M PDSCH REs, PBCH REs (both 'core' and 'repetition' parts along with corresponding cell reference signals) and other reference signals as configured for the full transmission sequence. This grid is also OFDM modulated to generate the associated time-domain baseband waveform. Plots are created to provide visualization of the RE assignment in the grid and of the magnitude of the baseband signal.

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With the toolbox you can configure, simulate, measure, and analyze end-to-end communications links. You can also create and reuse a conformance test bench to verify that your designs, prototypes, and implementations comply with the LTE standard.Using LTE Toolbox with RF instruments or hardware support packages, you can connect transmitter and receiver models to radio devices and verify your designs via over-the-air transmission and reception.

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**CHAPTER – 3**

**KEY COMPONENTS MODELED**

1. Physical Downlink Shared Channel (PDSCH):
   * The PDSCH carries user data and is an essential part of the downlink transmission.
   * It is responsible for delivering data to the user equipment (UE).
   * Our goal is to model the PDSCH waveform.
2. Physical Downlink Control Channel (PDCCH):
   * The PDCCH carries control information, including scheduling assignments and other critical instructions.
   * It informs the UE about resource allocation for the PDSCH.
   * We’ll also include the PDCCH transmission in our waveform.
3. Physical Control Format Indicator Channel (PCFICH):
   * The PCFICH provides information about the number of OFDM symbols used for PDCCH transmission in a subframe.
   * It helps the UE decode the PDCCH.
   * Our waveform will incorporate the PCFICH as well.

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### CHAPTER – 4

### LTE PHYSICAL LAYER CONCEPTS

Repetitions - To enable significantly extended coverage for LTE-M devices, repetitions for MPDCCH, PDSCH and PBCH were introduced for Cat-M devices in Release 13. This would provide at least 15dB performance improvement over pre-release 13 devices. MPDCCH can be repeated up to a maximum of 256 times, PDSCH up to 2048 and PBCH up to 5 including the 'core' part.

Narrowbands - LTE-M uses the concept of narrowbands to allocate subcarriers in the wideband LTE carrier for data and control channels. Each narrowband consists of 6 consecutive PRBs but not all PRBs are necessarily part of the narrowbands (dependent on the overall carrier BW).

Widebands - Release 14 LTE-M uses the concept of widebands to allocate higher bandwidth for the data channel. There can be one or more widebands, each consisting of 4 narrowbands or a single wideband consisting of 1,2 or 3 narrowbands. For a Cat-M2 device configured in CE mode A (DCI format 6-1A), the data channel is transmitted on a single wideband.

Frequency Hopping - Although a Release 13 eMTC device has an instantaneous bandwidth of 1.4MHz , it can access a wider LTE carrier through different narrowbands between the subframes. If the transmission involves repetition over multiple subframes, optional inter-subframe frequency hopping can be applied.

The frequency hopping happens between different narrowbands and in blocks of 1 to 16 subframes depending on CE mode. The hopping block length and hopping offset are cell-specific parameters. In the downlink, for both control and data, the frequency hopping can be over 2 narrowbands or 4 equally spaced narrowbands.

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**CHAPTER - 5**

**WORKING**

Here’s a step-by-step working:

1. Cell-wide Settings:
   * NDLRB: Number of Downlink Resource Blocks (DL-RB) = 6.
   * CyclicPrefix: Normal cyclic prefix.
   * PHICHDuration: Normal PHICH duration.
   * DuplexMode: Frequency Division Duplex (FDD) mode.
   * CFI: 4 PDCCH symbols.
   * Ng: HICH groups (set to “Sixth”).
   * CellRefP: 4 antenna ports.
   * NCellID: Cell ID.
   * NSubframe: Subframe number (considering subframe 0).
2. Subframe Resource Grid Generation:
   * Create an empty resource grid for one subframe using the lteDLResourceGrid function.
   * The resource grid dimensions:
   * Rows: Number of subcarriers (12 \* NDLRB).
   * Columns: Number of OFDM symbols (7 \* 2 slots).
   * Planes: Corresponding to the 4 antenna ports.
3. DL-SCH and PDSCH Settings:
   * Configure the DL-SCH and PDSCH using a structure (pdsch):
   * NLayers: Number of layers (set to 4 for transmit diversity).
   * TxScheme: Transmission scheme (TxDiversity).
   * Modulation: Modulation scheme (QPSK).
   * RNTI: 16-bit UE-specific mask.
   * RV: Redundancy Version.
4. PDSCH Mapping Indices Generation:

* Generate indices to map PDSCH complex symbols to the subframe resource grid using ltePDSCHIndices.

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**CHAPTER – 6**

**SOFTWARE USED FOR SIMULATION**

**MATLAB**

MATLAB stands for Matrix Laboratory. It is a high-performance language that is used for technical computing. It was developed by Cleve Molar of the company MathWorks.Inc in the year 1984.It is written in C, C++, Java. It allows matrix manipulations, plotting of functions, implementation of algorithms and creation of user interfaces.

Getting started with MATLAB:  
It is both a programming language as well as a programming environment. It allows the computation of statements in the command window itself.

* Command Window:

In this window one must type and immediately execute the statements, as it requires quick prototyping. These statements cannot be saved. Thus, this is can be used for small, easily executable programs.

* Editor (Script):

In this window one can execute larger programs with multiple statements, and complex functions These can be saved and are done with the file extension ‘.m ‘

* Workspace:  
  In this window the values of the variables that are created in the course of the program (in the editor) are displayed.

<="" b="" style="box-sizing: border-box;">  
This window displays the exact location(path) of the program file being created.

MATLAB Library comes with a set of many inbuilt functions. These functions mostly perform mathematical operations like sine, cosine and tangent. They perform more complex functions too like finding the inverse and determinant of a matrix, cross product and dot product.

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**CHAPTER – 7**

**PARAMETRIZATION**

### LTE Downlink Parameterization and Waveform Generation Functions:

The downlink waveform generator function requires a single hierarchical MATLAB structure which specifies the set of all parameters for the transport channels, physical channels and physical signals present in the output waveform. The generator function returns the time domain waveform, the populated resource grid and the parameter set used in the creation of the waveform.

The toolbox includes the lteRMCDL function, which can provide a fully populated parameter structure for the pre-configured Reference Measurement Channels (RMC) as well as custom configurations. This parameter structure can be directly used by the lteRMCDLTool function to generate the waveforms or it can be used as a template for creating waveforms with user specified values for any of the constituent channels or signals.

For example, changing the transmission scheme/mode, modulation scheme, code rate or changing the power level of the physical channels. It is important to note that all the user provided values are defined prior to calling the lteRMCDL function. This is because the lteRMCDL function does not overwrite any parameter values already defined at the input (except for read-only parameters). The following diagram shows parameterization for typical simulation setups.

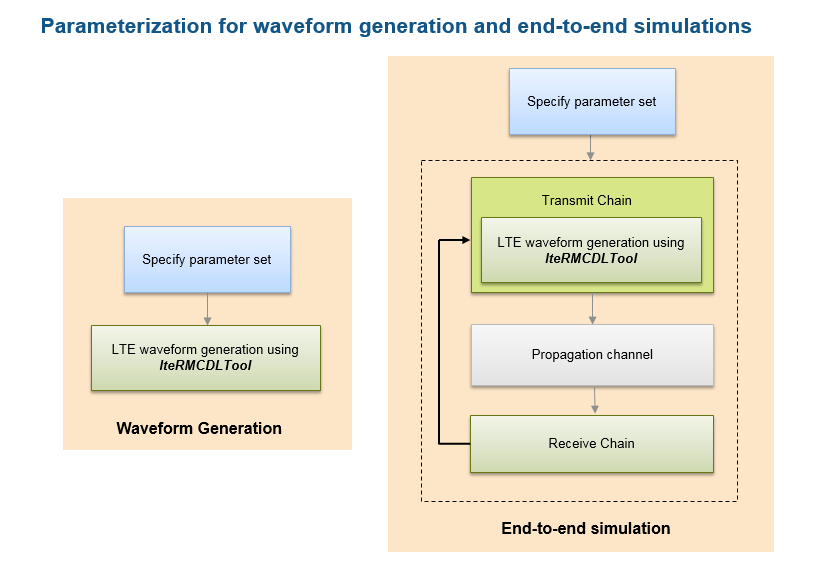
The LTE Toolbox supports different ways of specifying the parameter set defining the constituent physical channels and signals. These are explained further in subsequent sections:

Create the parameter set from important cell-wide and PDSCH parameters*:* The lteRMCDL function provides parameter expansion and transport block size processing from cell-wide and PDSCH parameters. All downlink and special (if TDD mode) subframes are assumed to be scheduled.

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This allows a subset of the parameters to be specified and the function then calculates compatible missing parameters to create the full set. This approach can be used in general to create configurations where subframe 5 is active.

Using one of the pre-defined parameter sets*:* The lteRMCDL function supports a number of standard defined parameter sets in the form of RMCs. If there is a configuration that exactly matches the requirements or if we want to generate a waveform corresponding to an RMC, we can use that RMC number directly for RMC table lookup and parameter set creation.



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**CHAPTER - 8**

**SIMULATION:**

**Code :**

enb.NDLRB = 6; % No of Downlink Resource Blocks(DL-RB)

enb.CyclicPrefix = 'Normal'; % CP length

enb.PHICHDuration = 'Normal'; % Normal PHICH duration

enb.DuplexMode = 'FDD'; % FDD duplex mode

enb.CFI = 3; % 4 PDCCH symbols

enb.Ng = 'Sixth'; % HICH groups

enb.CellRefP = 4; % 4-antenna ports

enb.NCellID = 10; % Cell id

enb.NSubframe = 0; % Subframe number 0

subframe = lteDLResourceGrid(enb);

pdsch.NLayers = 4; % No of layers

pdsch.TxScheme = 'TxDiversity'; % Transmission scheme

pdsch.Modulation = 'QPSK'; % Modulation scheme

pdsch.RNTI = 1; % 16-bit UE-specific mask

pdsch.RV = 0; % Redundancy Version

pdsch.PRBSet = (0:enb.NDLRB-1).'; % Subframe resource allocation

[pdschIndices,pdschInfo] = ...

ltePDSCHIndices(enb, pdsch, pdsch.PRBSet, {'1based'});

codedTrBlkSize = pdschInfo.G; % Available PDSCH bits

transportBlkSize = 152; % Transport block size

dlschTransportBlk = randi([0 1], transportBlkSize, 1);

% Perform Channel Coding

codedTrBlock = lteDLSCH(enb, pdsch, codedTrBlkSize, ...

dlschTransportBlk);

pdschSymbols = ltePDSCH(enb, pdsch, codedTrBlock);

subframe(pdschIndices) = pdschSymbols;

dci.DCIFormat = 'Format1A'; % DCI message format

dci.Allocation.RIV = 26; % Resource indication value

[dciMessage, dciMessageBits] = lteDCI(enb, dci); % DCI message

pdcch.NDLRB = enb.NDLRB; % Number of DL-RB in total BW

pdcch.RNTI = pdsch.RNTI; % 16-bit value number

pdcch.PDCCHFormat = 0; % 1-CCE of aggregation level 1

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% Performing DCI message bits coding to form coded DCI bits

codedDciBits = lteDCIEncode(pdcch, dciMessageBits);

pdcchInfo = ltePDCCHInfo(enb); % Get the total resources for PDCCH

pdcchBits = -1\*ones(pdcchInfo.MTot, 1); % Initialized with -1

% Performing search space for UE-specific control channel candidates

candidates = ltePDCCHSpace(enb, pdcch, {'bits','1based'});

% Mapping PDCCH payload on available UE-specific candidate. In this example

% the first available candidate is used to map the coded DCI bits.

pdcchBits( candidates(1, 1) : candidates(1, 2) ) = codedDciBits;

pdcchSymbols = ltePDCCH(enb, pdcchBits);

pdcchIndices = ltePDCCHIndices(enb, {'1based'});

% The complex PDCCH symbols are easily mapped to each of the resource grids

% for each antenna port

subframe(pdcchIndices) = pdcchSymbols;

cfiBits = lteCFI(enb);

pcfichSymbols = ltePCFICH(enb, cfiBits);

pcfichIndices = ltePCFICHIndices(enb);

% Map PCFICH symbols to resource grid

subframe(pcfichIndices) = pcfichSymbols;

surf(abs([subframe(:,:,1);subframe(end,:,1)]));

view(2);

h = rotate3d; setAllowAxesRotate(h,gca,false);

axis tight;

xlabel('OFDM Symbol');

ylabel('Subcarrier');

title('Resource grid');

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**CHAPTER - 9**

**RESULT:**

LTE waveform is generated using downlink transport and physical layer. To analyze or generate LTE waveforms, tools like LTE System Toolbox can be used.

The LTE Toolbox in MATLAB allows you to create standard baseband IQ downlink test model (E-TM) waveforms and reference measurement channel (RMC) waveforms.

We defined the DL-SCH and PDSCH parameters, such as the number of layers, modulation scheme, and redundancy version. Demodulating an LTE signal involves extracting information from the raw signal using advanced algorithms.

You can perform link-level simulations, verify your own LTE implementation, and even connect MATLAB to test and measurement instruments for live signal demodulation.

If you’re interested in exploring LTE waveforms further, consider using the LTE System Toolbox to acquire, modulate, and analyze LTE signals. LTE waveforms involves understanding their characteristics, performance, and how they interact with test and measurement equipment.

Waveform Acquisition and Analysis: You can capture LTE waveforms using test equipment and analyze them in MATLAB. This process involves visualization, decoding, and performance evaluation. Example of analysis include:

PDSCH Error Vector Magnitude (EVM) Measurement: Assessing the quality of the received signal.

LTE Downlink Adjacent Channel Leakage Power Ratio (ACLR) Measurement: Evaluating interference between adjacent channels.

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Output:

A screenshot of a graph

Description automatically generated

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**CHAPTER – 10**

**CONCLUSION**

Our goal was to create a time-domain waveform for the downlink transmission in an LTE system. We generated an empty resource grid for one subframe, considering the subcarrier and OFDM symbol dimensions. This modeling approach allows us to simulate and analyze LTE downlink channels effectively.

It aids in system design, optimization, and performance evaluation. Researchers and engineers can use these techniques to study channel behavior, evaluate link quality, and develop advanced communication systems. In conclusion, we understand LTE waveform modeling which empowers us to design robust communication networks and enhance wireless connectivity.

**COURSE OUTCOME**

CO2**:** Design the cellular system and improve the coverage and capacity of a system.

Thus, CO2 is justified.

CO3: Examine various mobile propagation model.

Thus, CO3 is justified.

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**CHAPTER – 11**

**REFERENCE**

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essentialhomestudio.com

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https://www.electronicsforu.com/

GitHub link for PBL

https://github.com/vishal9431/ct4g\_naveen\_kumar

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