Design, Analysis and Verification of 5G NR Waveforms using MATLAB

Lekha Wireless Solutions
Agenda

- Introduction
- Brief Introduction to 5G
- 5G @Lekha
- Design and Verification Approach
- MATLAB Based Analysis & Results
- Demo
- Summary and Conclusions
Introduction—Lekha Wireless Solutions

- Started in 2010, Reaching 9 years of Success
- Focused on Wireless Infrastructure Products, IPs & Services
- Engineering Team of 120+ with average experience of 7+ years
- Engineering Expertise across all Wireless Domain Verticals of SW and HW driving Research, Design & Development and Manufacturing
- Ranked among fast 50 Growing Technology company in India by Deloitte for year 2014 and 2013
- Successful launch and deployment of WaveGuru SDR, Laksha, WaveDyut and Vyapi Radio Products for Industrial IOT, Private Networks and Tactical Communications
- IP and Reference Solutions for 4G and 5G
  - LTE eNB, LTE UE, NB-IoT UE and 5G NR gNB
- IDEX (Ministry of Defence, Govt of India) Winner, 2019
Introduction - Product Portfolio

Solutions – Defence Networks

Laksha
- DSSS, SOQPSK and Single Carrier Waveforms
- Telemetry PTP Links
- Low Latency, High Reliable Links
- Customers: Missile & Satellite Networks

WaveDyut
- COFDM Waveforms
- High Throughput PTP, PTMP Links
- Customers: UGV, UAV Networks Wireless Backhaul Solutions

Vyapi
- 3GPP OFDM, SC-FDMA Waveform
- 10W Macro eNB
- 2W Small Cell NIB
- Outdoor Vehicle Mount UE
- Customers: Tactical Networks Private Networks

Solutions – Commercial Private Networks

5G IP
- 5G NR eMBB Waveforms
- 100 MHz, 200 MHz BW
- Massive MIMO
- NB-IOT
- Reference Solutions
Brief Intro to 5G – Highlights

- 5GNR 3gpp in Release 15 and Release 16
- 5G Tiers include eMBB mMTC and URLCC
- eMBB for High throughputs
- mMTC provides machine to machine communications and IOT applications
- URLCC end to end latency ~1ms
- 5G cloud architecture, network slices enabling low CAPEX and OPEX costs
Brief Intro to 5G – Signal Chain

From MAC:
1. Payload Generation
2. Channel Encoder
3. Rate Matching
4. Scrambling
5. Modulation
6. Layer Mapping
7. IFFT
8. Subcarrier Mapping
9. MIMO Tx Processing

RF out:
- Cyclic Prefix Extension
- MIMO Tx Processing

RF in:
1. Cyclic Prefix Removal
2. FFT
3. Subcarrier Demapping
4. Channel Estimation
5. Channel Equalization
6. Inverse DFT (*)

To MAC:
1. Payload Extraction
2. Channel decoder
3. De Rate Matching
4. De Scrambling
5. De Modulation
6. De Interleaver

Per User, Per Antenna, User to RF crossover

(*) Optional Block
## 5G Work @Lekha: Small Cell gNB IP

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3GPP Standard Specification</td>
<td>Release 15 (FR1)</td>
</tr>
<tr>
<td>2</td>
<td>Channels supported</td>
<td>SS Block (PSS, SSS, PBCH)</td>
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<tr>
<td></td>
<td></td>
<td>DL Control Channel (PDCCH)</td>
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<tr>
<td></td>
<td></td>
<td>DL Shared Channel (PDSCH)</td>
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<tr>
<td></td>
<td></td>
<td>Random Access Channel (PRACH)</td>
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<td></td>
<td></td>
<td>UL Control Channel (PUCCH)</td>
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<td></td>
<td></td>
<td>UL Shared Channel (PUSCH)</td>
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<tr>
<td>3</td>
<td>Sub Carrier Spacing</td>
<td>15kHz, 30kHz, 60kHz</td>
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<tr>
<td>4</td>
<td>Bandwidth</td>
<td>Upto 100MHz (FR1)</td>
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<tr>
<td>5</td>
<td>Modulation Scheme</td>
<td>QPSK, QAM16, QAM64, QAM256</td>
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<tr>
<td>6</td>
<td>Number of Antenna</td>
<td>4T 4R</td>
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<tr>
<td>7</td>
<td>Number of Layers</td>
<td>DL 4 Layers / UL 2 Layers</td>
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<tr>
<td>8</td>
<td>Duplexing Mode</td>
<td>FDD, TDD</td>
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<tr>
<td>9</td>
<td>System Throughput</td>
<td>Upto 2.4Gbps</td>
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## Design & Verification Approach

<table>
<thead>
<tr>
<th>SN</th>
<th>Description</th>
<th>Test Objective</th>
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<tbody>
<tr>
<td>1</td>
<td>Module Level Functional Validation</td>
<td>Ensures the Developer to deliver for Integration phase</td>
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<td>2</td>
<td>Module Level Performance Validation &amp; Design Improvements</td>
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<td>3</td>
<td>Integration Level Signal Chain Validation</td>
<td>Ensures the Developer to deliver for End to End System Test</td>
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<td>4</td>
<td>3GPP 38.141-1 Conducted Conformance Testing</td>
<td>Stack Conformance Test for Product Integration</td>
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</table>
GUI -> PHY Configuration

Frequency Band: fr1
ARFCN: 422000
Bandwidth(MHz): 5
Numerology: 0
Operation Band: nr1
Frequency(MHz): 2110
SCS(KHz): 15
Sampling Rate(KHz): 7680

Next  View Frame  Generate
## GUI → Frame Display

### 5G NR Frame Structure

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<thead>
<tr>
<th>Subframe 0</th>
<th>Subframe 1</th>
<th>Subframe 2</th>
<th>Subframe 3</th>
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<th>Subframe 7</th>
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<th>Subframe 12</th>
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MATLAB Verification -> SSB Sync Detection
MATLAB Verification -> PBCH Decoding

Received PBCH Constellation

Equalized PBCH Constellation
MATLAB Verification -> PDCCH Decoding
MATLAB Verification -> PDSCH 1 Layer

Received PDSCH Constellation for 256QAM at 50 dB for 100MHz

Equalized PDSCH Constellation for 256QAM at 50 dB for 100MHz
Single User MIMO 4 Layer with AWGN channel
SNR -> 26dB

Received PDSCH constellation for 256QAM at 26 dB for 100MHz
Single User MIMO with 4 Layers decoding at SNR->37dB

Modulation : 256QAM  SNRdB = 37dB  Bandwidth = 100MHz  Channel Type = CDL
Single User MIMO with 4 Layers decoding at SNR->50dB

Modulation : 256QAM     SNRdB = 50dB     Bandwidth = 100MHz     ChannelType = CDL

Received PDSCH Constellation

Equalized PDSCH Constellation
‘Polar Coding’ technique has been included in latest 3GPP release for 5G standards in two channels namely SSB and PDCCH.

‘The LDPC Coding’ method has been adopted by 3GPP for 5G New Radio (NR) Uplink and downlink shared channel, i.e PDSCH and PUSCH.

The C Encoder and Decoder test benches for Polar and LDPC are functionally validated independently with MATLAB as reference.

Also, the Standalone end to end C test benches for Polar and LDPC are created for the Performance Validation and the BER Plots are plotted and are compared against the MATLAB.
Performance Validation of C Encoder - Decoder

Input bits → LDPC Encoder → AWGN/Channel Models → LDPC Decoder → Output bits

Compare input and output
Summary and Conclusions

- Why Lekha 5G NR gNB IP
  - Complete C Reference Availability – Enables Platform Flexibility
  - RTL based UL BRP, DL BRP and Precoder Blocks for Scalable Design
  - Reference Solutions for FR1 and FR2 (IF based)

- Why MATLAB 5G Toolbox For Validation
  - IP Maturity at Module Level, Integration Level and Product Solution Level
  - Automated Test Bench For Different User Configurations using MATLAB Toolbox – Enables Regression Test suit for PHY Layer Stack
  - Easier Issue Analysis & Bug finding due to low level access in MATLAB 5G Toolbox
5G Toolbox – PHY Layer Functions

NR Processing Subsystems
- LPDC & polar coding
- CRC, segmentation, rate matching
- Scrambling, modulation, precoding

NR Downlink and Uplink Channels and Physical Signals
- Synchronization & broadcast signals
- DL-SCH & PDSCH channels
- DCI & PDCCH channels
- UCI, PUSCH, and PUCCH channels

MIMO Propagation channels
- TDL & CDL channel models
5G Toolbox applications & use-cases

End-to-end link-level simulation
- Transmitter, channel model, and receiver
- Analyze bit error rate (BER), and throughput

Waveform generation and analysis
- Parameterizable waveforms with New Radio (NR) subcarrier spacings and frame numerologies

Golden reference design verification
- Customizable and editable algorithms as golden reference for implementation
5G Toolbox has open customizable algorithms

- All functions are open, editable, customizable MATLAB code
- C/C++ code generation: Supported with MATLAB Coder
How to learn more

- Go to 5G Toolbox product page
  www.mathworks.com/products/5g
  5G Development with MATLAB (ebook)

- Watch Videos & Webinars
  5G: Model, Simulate, Design, and Test 5G Systems with MATLAB
  Waveform Generation and Testing with SDR and RF instruments
Thank You