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

Lekha Wireless Solutions
• 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
- Focussed 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:
- Payload Generation
- Channel Encoder
- Rate Matching
- Scrambling
- Modulation
- Layer Mapping

RF out:
- Cyclic Prefix Extension
- IFFT
- Subcarrier Mapping
- MIMO Tx Processing

RF in:
- Cyclic Prefix Removal
- FFT
- Subcarrier Demapping
- Channel Estimation
- Channel Equalization
- Inverse DFT (*)

To MAC:
- Payload Extraction
- Channel decoder
- De RateMatching
- De Scrambling
- De Modulation
- 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>
</tr>
<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>
</tr>
<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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<tr>
<td></td>
<td></td>
<td>UL Shared Channel (PUSCH)</td>
</tr>
<tr>
<td>3</td>
<td>Sub Carrier Spacing</td>
<td>15kHz, 30kHz, 60kHz</td>
</tr>
<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>
</tr>
<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>
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<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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<tr>
<td>2</td>
<td>Module Level Performance Validation &amp; Design Improvements</td>
<td></td>
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<tr>
<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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<tr>
<td>4</td>
<td>3GPP 38.141-1 Conducted Conformance Testing</td>
<td>Stack Conformance Test for Product Integration</td>
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</tbody>
</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
## SGNR Frame Structure

<table>
<thead>
<tr>
<th>Subframe 0</th>
<th>Subframe 1</th>
<th>Subframe 2</th>
<th>Subframe 3</th>
<th>Subframe 4</th>
<th>Subframe 5</th>
<th>Subframe 6</th>
<th>Subframe 7</th>
<th>Subframe 8</th>
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### Diagram

[Diagram of SGNR Frame Structure with color-coded slots for SSS, PSS, PBCH, DMRS, PDCCH, and PDSCH.]
MATLAB Verification -> SSB Sync Detection

PSS Correlations (time domain)

SSS Correlations (frequency domain)

PBCH DM-RS Correlations (frequency domain)
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
Module Level Verification for Polar and LDPC

➢ ‘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
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