Q&A

Please fill the session-related questions into the Q&A sheet in your registration kit and hand over the sheet to our promoters
MATLAB EXPO 2019

5G New Radio Fundamentals: Understanding the Next Generation of Wireless Technology

Tabrez Khan
Application Engineering
Introduction to 5G Physical Layer

- 5G requirements and use cases
- Key 5G physical layer features
- Physical layer simulation with 5G Toolbox
5G Use Cases and Requirements

- eMBB (enhanced Mobile Broadband)
  - High data rates

- mMTC (massive Machine Type Communications)
  - Large number of connections

- URLLC (Ultra-Reliable and Low Latency Communications)
  - Low latency
# 5G vs LTE: Main Physical Layer Differences

<table>
<thead>
<tr>
<th></th>
<th>LTE</th>
<th>5G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use cases</strong></td>
<td>Mobile broadband access (MTC later)</td>
<td>More use cases: eMBB, mMTC, URLLC</td>
</tr>
<tr>
<td><strong>Latency</strong></td>
<td>~10 ms</td>
<td>&lt;1 ms</td>
</tr>
<tr>
<td><strong>Band</strong></td>
<td>FR1 (&lt; 6 GHz)</td>
<td>FR1 (&lt;6 GHz), FR2 (23-53 GHz)</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>Up to 20 MHz</td>
<td>Up to 100 MHz below 6 GHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Up to 400 MHz above 6 GHz</td>
</tr>
<tr>
<td><strong>Subcarrier spacing</strong></td>
<td>Fixed</td>
<td>Variable</td>
</tr>
<tr>
<td><strong>Freq allocation</strong></td>
<td>UEs need to decode the whole BW</td>
<td>Use of bandwidth parts</td>
</tr>
<tr>
<td><strong>“Always-on” signals</strong></td>
<td>Cell specific RS, PSS, SSS, PBCH</td>
<td>Reduced always-on signals, the only one is the SS block</td>
</tr>
</tbody>
</table>
5G Waveforms, Frame Structure and Numerology

- Waveforms
- Resource elements and blocks
- Frame structure
- Variable subcarrier spacing
- Bandwidth parts
Waveforms

- OFDM with cyclic prefix: CP-OFDM
- Increased spectral efficiency with respect to LTE, i.e. no 90% bandwidth occupancy limitation
- Need to control spectral leakage:
  - F-OFDM
  - Windowing
  - WOLA
Resource Elements and Resource Blocks

**Resource block**: 12 subcarriers (frequency domain only, no time duration (*)

**Resource element**: smallest physical resource

(*) unlike LTE: 1 RB = 12-by-7
Frame Structure

- 10ms frames
- 10 subframes per frame
- Variable number of slots per subframe
- 14 OFDM symbols per slot (normal CP)
- Variable number of OFDM symbols per subframe (different from LTE)
Variable Subcarrier Spacing

<table>
<thead>
<tr>
<th></th>
<th>Slot configuration 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcarrier spacing (kHz)</td>
<td>15       30     60   120  240</td>
</tr>
<tr>
<td>Symbol duration (no CP) (μs)</td>
<td>66.7  33.3  16.6  8.33  4.17</td>
</tr>
<tr>
<td>Nominal max BW (MHz)</td>
<td>49.5     99     198  396  397.4</td>
</tr>
<tr>
<td>Min scheduling interval (ms)</td>
<td>1     0.5    0.25  0.125 0.0625</td>
</tr>
</tbody>
</table>

- Subcarrier spacing can be a power-of-two multiple of 15kHz
- Waveforms can contain a mix of subcarrier spacings
- This flexibility is required to support different services (eMBB, mMTC, URLLC) and to meet short latency requirements
- Increased subcarrier spacing can also help operation in mmWave frequencies
## Slots and OFDM Symbols (Normal CP)

<table>
<thead>
<tr>
<th>Subcarrier spacing (kHz)</th>
<th>Symbols/slot</th>
<th>Slots/frame</th>
<th>Slots/subframe</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>14</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>14</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>60</td>
<td>14</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>120</td>
<td>14</td>
<td>80</td>
<td>8</td>
</tr>
<tr>
<td>240</td>
<td>14</td>
<td>160</td>
<td>16</td>
</tr>
</tbody>
</table>

- **Subframe**
- **Slot:** 1 ms
  - **15 kHz**
  - **Slot:** 0.5 ms
  - **30 kHz**
    - **Slot:** 0.25 ms
Bandwidth Parts (BWP)

- Carrier bandwidth divided into BWPs

- A BWP is characterized by
  - Subcarrier spacing
  - Cyclic prefix

- Addresses the following issues:
  - Some devices may not be able to receive the full BW
  - Bandwidth adaptation: reduce energy consumption when only narrow bandwidth is required
Bandwidth Parts (BWP)

- A UE can be configured with up to 4 bandwidth parts
- Only one bandwidth part is active at a time
- UE is not expected to receive data outside of active bandwidth part
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 waveform generation

- 5G Toolbox supports downlink & uplink waveform generation

- Generated waveforms feature:
  - mixed numerology
  - multiple bandwidth parts
  - multiple PDSCHs / PUSCHs
  - multiple PDCCHs / PUCCHs
  - fully parameterizable SS bursts
  - multiple CORESETS and search spaces

Power levels have been modified to improve visualization
5G NR Downlink Carrier Waveform Generation
Key Reference Application Examples

- **NR Synchronization Procedures**
  - **Downlink:**
    - NR PDSCH BLER and Throughput Simulation
    - NR Downlink Waveform Generation
  - **Uplink:**
    - NR PUSCH BLER and Throughput Simulation
    - NR Uplink Waveform Generation
5G Toolbox has open customizable algorithms

- All functions are open, editable, customizable MATLAB code
- C/C++ code generation: Supported with MATLAB Coder
Over-the-Air Testing with SDR and RF Instruments

Demo Station: Design and Prototype Wireless Systems
Call to Action

- Learn more about RF and antenna arrays

Seamless System Design of RF Transceivers and Antennas for Wireless Systems
12:45–13:15

Wireless engineers are pursuing 5G and other advanced technologies to achieve gigabit data rates, ubiquitous coverage, and massive connectivity for many applications such as IoT and V2X. The need to improve performance and coexist with multiple communications standards and devices while reducing the overall area and power imposes challenging requirements on RF front ends. Gaining an insight into such complex systems and performing architectural analysis and tradeoffs require a design model that includes DSP, RF, antenna and channel, as well as impairments.

In this talk, you will learn how to model antenna arrays and integrate them in RF front ends for the development of wireless communications, including:

- Analyzing the performance of antennas with arbitrary geometry
- Performing array analysis by computing coupling among antenna elements
- Modeling the architecture of RF front ends
- Developing baseband and RF beamforming algorithms

Vidya Viswanathan,
MathWorks
5G Customer Successes

Qualcomm (UK)

Using MATLAB to Develop 5G RF Front End Components and Algorithms

Saeid Lynch, Qualcomm UK Ltd.

Customer UK develops 5G RF front end components and antenna array technology for 5G mobile devices that support more than 10 different bands. In 5G, the number of possible waveform combinations is greater than 268, making device validation much more complex and time-consuming.

The Qualcomm filter, in collaboration with MathWorks, developed a complete model of the Teranet filter path with high-fidelity specifications and waveform accuracy models. They used simulations to predict the system performance. The system design parameters can be automatically generated as a team of waveform components. The team can generate automated waveform libraries from the MATLAB models, using live time in human-driven development and automatic waveform synthesis for customers.

Advantages of using MATLAB:

- Fully model and verify the RF components and key analog and digital components.
- Reduce time to market and substantially reduce time to market.
- Enable a small team to execute a scalable and maintainable set of tools.
- Streamline the cost of developing separate tools, unlike different instrumentations.

Huawei (China)

Developing a Radio Frequency System for 5G Wireless at Huawei

Enli Zhu, Huawei

The company collaborates with MathWorks to develop a system that ensures wireless communication between core systems, wireless communication devices, and base stations. The company can now design and develop an end-to-end system from the core to the edge. The solution enables various network operators to work together on 5G network design and deployment.

Advantages of using MATLAB:

- Real-time simulation and design with MATLAB and Simulink.
- Achieving 50% design overlap time.
- Cost-effective and flexible design process.
- Improved design accuracy and performance.

Convida (USA)

Advancing the 5G Wireless Standard at Convida: Wireless: An Insider Look

Convida is a partner between the Corporation of America and the University of Stanford. They develop advanced wireless communication technologies and standardize the wireless communication process. Today, they have successfully developed a model-based design platform that supports the entire development process.

Advantages of using MATLAB:

- Fully model and verify the RF components and key analog and digital components.
- Reduce time to market and substantially reduce time to market.
- Enable a small team to execute a scalable and maintainable set of tools.
- Streamline the cost of developing separate tools, unlike different instrumentations.

Nokia (Finland)

5G Development with Model-Based Design at Nokia

Sanni Repo, Nokia

Nokia’s Model-Based Design (MBD) platform is used to automate development of the digital network and 5G base station. The platform supports specific requirements across a wide range of target devices to support different scenarios, thereby reducing development time and costs.

Advantages of using MATLAB:

- Efficient IP development
- Small teams can do more and work faster
- Use MATLAB code and Simulink models throughout the development process
- Unify R&D, test, and hardware development

Working with MathWorks has enabled Nokia to establish a model-based design mindset, which has brought flexibility, scalability, and reliability to work through 5G. Nokia design flows have improved design time by 50%.

Available on the 5G Technology web page
How to learn more

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

- Watch Videos & Webinars
  [5G: Model, Simulate, Design, and Test 5G Systems with MATLAB](www.mathworks.com/products/5g)
  [Waveform Generation and Testing with SDR and RF instruments](www.mathworks.com/products/5g)
MATLAB EXPO 2019

Email: tkhan@mathworks.in
LinkedIn: https://www.linkedin.com/in/tabrez-khan-8756615a/
Thank You