Technische Grundlagen des neuen 5G-Funkstandards

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Introduction to 5G PHY
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
  - Increased bandwidth efficiency

- **mMTC (massive Machine Type Communications)**
  - Large number of connections
  - Energy efficiency and low-power operation

- **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>
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<tr>
<td>Use cases</td>
<td>Mobile broadband access (MTC later)</td>
<td>More use cases: eMBB, mMTC, URLLC</td>
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<tr>
<td>Latency</td>
<td>~10 ms</td>
<td>&lt;1 ms</td>
</tr>
<tr>
<td>Band</td>
<td>Below 6 GHz</td>
<td>Up to 60 GHz</td>
</tr>
<tr>
<td>Bandwidth</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>Subcarrier spacing</td>
<td>Fixed</td>
<td>Variable</td>
</tr>
<tr>
<td>Freq allocation</td>
<td>UEs need to decode the whole BW</td>
<td>Use of bandwidth parts</td>
</tr>
<tr>
<td>“Always on” signals</td>
<td>Used: Cell specific RS, PSS, SSS, PBCH</td>
<td>Avoid always on signals, the only one is the SS block</td>
</tr>
</tbody>
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## 5G Physical Layer Features

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<td>Downlink Control</td>
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<td>CORESETs</td>
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<td>Uplink Control</td>
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To learn about all topics, visit online videos: [URL]
5G Transport Channels, Physical Channels, and Physical Signals
Transport Channels

- Offer information transport services to MAC layer
- Carry control/signalling and data
- Define the scrambling, channel coding, interleaving and rate matching to apply to the information

<table>
<thead>
<tr>
<th>DL Transport Channels</th>
<th>UL Transport Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DL-SCH</strong></td>
<td><strong>UL-SCH</strong></td>
</tr>
<tr>
<td>DL shared channel</td>
<td>UL shared channel</td>
</tr>
<tr>
<td><strong>DCI</strong></td>
<td><strong>UCI</strong></td>
</tr>
<tr>
<td>Downlink control info</td>
<td>Uplink control info</td>
</tr>
<tr>
<td><strong>BCH</strong></td>
<td><strong>RACH</strong></td>
</tr>
<tr>
<td>Broadcast channel</td>
<td>Random access channel</td>
</tr>
<tr>
<td><strong>PCH</strong></td>
<td></td>
</tr>
<tr>
<td>Paging channel</td>
<td></td>
</tr>
</tbody>
</table>
Physical layer channels and signals

- Shared, control and broadcast channels
  - Downlink: DL-SCH / PDSCH, PDCCH, BCH / PBCH
  - Uplink: UL-SCH, PUSCH, PUCCH
- Synchronisation and reference signals
  - PSS, SSS, DM-RS
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 element**: smallest physical resource
- **Resource block**: 12 subcarriers (frequency domain only, no time duration (*)

(*) 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>Subcarrier spacing (kHz)</th>
<th>Slot configuration 0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Symbol duration (no CP) (μs)</td>
<td>66.7</td>
</tr>
<tr>
<td>Nominal max BW (MHz)</td>
<td>49.5</td>
</tr>
<tr>
<td>Min scheduling interval (ms)</td>
<td>1</td>
</tr>
</tbody>
</table>

- Subcarrier spacing can be a power-of-two multiple of 15kHz
- Waveforms can contain a mix of subcarrier spacings
- Addresses the following issues
  - 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: 15 kHz

Slot: 1 ms

Subframe: 30 kHz

Slot: 0.5 ms

Subframe: 60 kHz

Slot: 0.25 ms

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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
Downlink Data in 5G NR
**Downlink Shared Channel (DL-SCH)**

- Carries user data
- Can also carry the System Information Block (SIB)
- Up to 2 codewords and 8 layers
- Mapped to the PDSCH
- Main difference with LTE: use of LDPC coding
Physical Downlink Shared Channel (PDSCH)

- Highly configurable
- Parameters are configured by:
  - DCI (Downlink Control Information)
  - RRC (Radio Resource Control)
PDSCH Modulation Schemes

nrSymbolModulate(in, modulation)

<table>
<thead>
<tr>
<th>Modulation scheme</th>
<th>Modulation order</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>2</td>
</tr>
<tr>
<td>16QAM</td>
<td>4</td>
</tr>
<tr>
<td>64QAM</td>
<td>6</td>
</tr>
<tr>
<td>256QAM</td>
<td>8</td>
</tr>
</tbody>
</table>
PDSCH Multi-antenna Precoding

- Achieves beamforming and spatial multiplexing
- Maps layers to antenna port
- Uses a precoding matrix $W_{N\text{antennas} \times N\text{layers}}$
- DM-RS has to go through the same precoding operation
Mapping to Physical Resources

\[
pdschGrid(pdschAntIndices) = pdschSymbols;
\]
PDSCH Allocation Example

- Can use a full slot or part of a slot
- Partial slot allocation: good for low latency applications
PDSCH Allocation Example

- Can use a full slot or part of a slot
- Partial slot allocation: good for low latency applications
Introducing 5G Toolbox
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
NR Processing Subsystems
- LPDC & polar coding
- CRC, segmentation, rate matching
- Scrambling, modulation, precoding

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

MIMO Prop channels
- TDL & CDL channel models
5G Toolbox has open customizable algorithms

- All functions are open, editable, customizable MATLAB code
- C/C++ code generation: Supported with MATLAB Coder
### 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

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**5G NR Uplink Carrier Waveform Generation**

This example implements a 5G NR uplink carrier waveform generator using 5G Toolbox(TM).

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**Introduction**

This example shows how to parameterize and generate a 5G New Radio (NR) uplink waveform. The following channels and signals are generated:

- PUSCH and its associated DM-RS
- PUCCH and its associated DM-RS

This example supports the parameterization and generation of multiple bandwidth parts (BWP). Multiple instances of the PUSCH and PUCCH channels can be generated over the different BWPs.

**Carrier Configuration**

This section sets the overall carrier bandwidth in resource blocks, the cell ID, and the length of the generated waveform in subframes. You can visualize the generated resource grids by setting the [DisplayGrids] field to 1.

```matlab
carrier = []; % Carrier in MHz numerology
carrier.MHz = 200; % Cell ID
carrier.NcellID = 0; % Number of subframes in generated waveform [1,2,4,8 slots per subframe]
carrier_DISPLAYGrids = 1; % Display the resource grids after signal generation
```

**Bandwidth Parts**

A BWP is formed by a set of contiguous resources sharing a numerology on a given carrier. This example supports the use of multiple BWPs using a struct array. Each entry in the array represents a BWP. Each BWP can have different subcarrier spacings (SCS), use different cyclic prefixes (CP) lengths and span different bandwidths. The [ResourceLocation] parameter controls the location of the BWP in the carrier. This is expressed in terms of the BWP numerology. Different BWPs can overlap with each other.

```matlab
bwp = [ ];
bwp(1).SCScarrierSpacing = 25; % BWP Subcarrier Spacing
bwp(1).cyclicPrefix = 'Normal'; % BWP cyclic prefix for 15 kHz
bwp(1).N = 25; % Number of BWPs
bwp(1).NoffSet = 10; % Position of BWP in carrier
```
How to learn more

- View the “5G PHY Overview” instructional videos https://mathworks.com/videos/series/5g-explained.html

- 5G Toolbox product information www.mathworks.com/products/5g
  - Watch the 5G Toolbox video
  - Review the 5G Toolbox documentation

- ‘MATLAB for 5G’ – overview of product range
  - www.mathworks.com/solutions/wireless-communications/5g

- Ask MathWorks for a trial license!!!
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