MATLAB EXPO 2021

5G and Wireless Design

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3 Topics We Cover Today

Ubiquity
Model 5G/Wireless connectivity systems and standards

Complexity
Integrate and simulate multi-domain designs from antenna-to-bits

Efficiency
Iterate, optimize and verify design implementations
Wireless Communication is Everywhere

Connected Devices
- Automotive
- Industrial
- Smart home
- Smart city
- Medical

Communications Infrastructure

Semiconductors and components:
Baseband, RF, Antenna

Mobile devices
Common Challenges of Wireless Design

Physical Layer Design
- OFDMA
- Mu-MIMO
- Channel estimation/Equalization
- Modulation & Coding
- RF Linearization (PA and DPD)

System Engineering
- mmWave
- Link Budget Analysis
- Capacity & throughput
- System-level simulation
- Co-Existence and Interference

Ubiquity
Ubiquitous Connectivity

Deployment & Verification
- Fixed-point design
- Parallelism
- Area-speed tradeoffs
- Over-the-air testing
- Rapid Prototyping and IP design

Efficiency
Efficient deployment & testing
Ubiquity

Model 5G/Wireless connectivity systems and standards

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Ubiquitous connectivity – technologies & standards

- Personal Area Network
- Local Area Network
- Wide Area Network
- Cellular
- Wi-Fi
- Satellite communications

Technologies & standards include:

- Bluetooth
- Wi-Fi
- 5G
- GNSS
- CCSDS
- DVB-S2X

These technologies and standards enable ubiquitous connectivity.
5G: A Megatrend & Driving Force

Connectivity & Positioning (UWB, BLE, Wi-Fi)

Ultra Reliable & Low Latency
- 1ms Latency
- $10^{-9}$ Error-rate, Ultra reliability

massive Machine-Type Communications
- 1 million device connections/km²
- High energy efficiency

5G Cellular

Autonomous Driving / V2X

Connected Car

Connected Factory

Satellite

UAVs

SatCom and UAVs

5G: A Megatrend & Driving Force

Data center

Ultra Reliable & Low Latency

massive Machine-Type Communications

Ultra Reliable & Low Latency

massive Machine-Type Communications
Trend: Emerging Satellite communications

Driven by development of high-speed internet connectivity

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**Link Budget Analysis**

<table>
<thead>
<tr>
<th>Name</th>
<th>L1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (km)</td>
<td>3.6595e+02</td>
</tr>
<tr>
<td>Elevation (deg)</td>
<td>30.2176</td>
</tr>
<tr>
<td>Tx ERP (dB)</td>
<td>51</td>
</tr>
<tr>
<td>Polarization loss (dB)</td>
<td>3.0103</td>
</tr>
<tr>
<td>FSPL (dB)</td>
<td>186.6387</td>
</tr>
<tr>
<td>Received isotropic power (dBW)</td>
<td>-141.6490</td>
</tr>
<tr>
<td>C/No (dB/Hz)</td>
<td>87.5502</td>
</tr>
<tr>
<td>C/N (dB)</td>
<td>20.1687</td>
</tr>
<tr>
<td>Received Eb/No (dB)</td>
<td>17.9502</td>
</tr>
<tr>
<td>Margin (dB)</td>
<td>5.9692</td>
</tr>
</tbody>
</table>

**Orbit Propagation and Visualization; Access and Link Analysis**

**Waveform Generation**

**End-to-End Simulations**
Trend: Wi-Fi evolution – Driven by IoT

802.11ac ➔ 802.11ax Wi-Fi 6
100s of Mbps, high efficiency with lots of devices

802.11ax ➔ 802.11be Wi-Fi 7
Gbps, reduced latency and jitter

802.11az - Positioning

More devices & dense environments

Industry 4.0

Direction Finding & Localization
Common use-cases of standard-based connectivity design

Waveform Generation

Link-level Simulation

Interference & Coexistence

Network Simulation

AI Workflow
Pre-trained models, training, evaluation, validation
Wireless Waveform Generator App

- Interactive waveform generation
- 5G NR off-the-shelf waveforms:
  - NR-TMs / FRCs
- Custom downlink & uplink waveforms
  - New in the App in R2021a
IEEE 802.11be Waveform Generation
End-to-end Link-level Simulation

End-to-End DVB-S2 Simulation with RF Impairments and Corrections

5G NR PDSCH Throughput

802.11ax Downlink OFDMA and Multi-User MIMO Throughput Simulation
Interference & Coexistence

- 2.4 GHz

- 5/6 GHz

- 60 GHz
Example - 802.11ax RF receiver with 5G interference

<table>
<thead>
<tr>
<th>Transmitted waveform</th>
<th>802.11ax at 5950MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interferer</td>
<td>NR-TM at 5980MHz</td>
</tr>
<tr>
<td>Tests</td>
<td>- Channel power</td>
</tr>
<tr>
<td></td>
<td>- EVM per subcarrier</td>
</tr>
<tr>
<td></td>
<td>- EVM per OFDM symbol</td>
</tr>
</tbody>
</table>

802.11ax RF Receiver

RF Blockset

WLAN Toolbox

PHY Decode and Measurements
5G NR System-level Simulations

- Evaluating performance of different schedulers
  - Round-robin, proportionally fair, best CQI

![Diagram showing Processing Loop Operations for PUSCH Transmission]

![Graphs showing Throughput, goodput, buffer status]
Deep Learning for Wireless Workflow

Pre-labeled synthesized data → Transform → Train Network → Trained Model

New Signal → Transform → Pre-Trained Model → Classification
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Integrated Multi-domain Modeling Complexity
Workflow for Antenna-to-Bit Multi-Domain Design

1. Design an array
2. Add channel model
3. Hybrid beamforming
4. Specify RF front end
Design, Analyze and Visualize Antenna Elements and Arrays

- Get started with antenna and array catalog, and apps
- Perform full-wave EM simulation
- Improve the performance using surrogate optimization
- Design and fabricate PCBs with Gerber file generation
- Analyze the effects of installation on large platforms
Architecture Exploration for Hybrid Beamforming

- Thermal and phase noise
- Image rejection
- Channel selection
- Non-linearity
- S-parameters

Baseband and RF beamsteering
Power Amplifier Linearization: 5G Simulation Results

1. Generate 5G waveforms

   \texttt{rc = "NR-FRI-TM3.1";} \% Reference channel (NR-TM or FRC)
   \texttt{bw = "100MHz";} \% Channel bandwidth
   \texttt{scs = "30kHz";} \% Subcarrier spacing
   \texttt{dm = "FDD";} \% Duplexing mode

2. Model PA memory and non-linearity

\[ y_{\text{DPD}}(n) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} a_{km} x(n-m) x(n-m)^k \]

Memory depth  Degree of non-linearity

3. Measure EVM

   \begin{itemize}
   \item Low edge RMS EVM, Peak EVM: slot 17: 0.789 3.1465
   \item High edge RMS EVM, Peak EVM: slot 17: 0.794 3.2105
   \item Low edge RMS EVM, Peak EVM, slot 18: 0.794 3.1515
   \item High edge RMS EVM, Peak EVM, slot 18: 0.770 3.2171
   \item Low edge RMS EVM, Peak EVM, slot 19: 0.770 3.1525
   \item High edge RMS EVM, Peak EVM, slot 19: 0.783 3.2155
   \end{itemize}

Averaged low edge RMS EVM, frame 0: 0.7835
Averaged high edge RMS EVM, frame 0: 0.7835
Averaged overall RMS EVM: 0.7835
Peak EVM = 3.7347%

4. Create a RF system including DPD
Propagation Channels

- Scattering MIMO channel
- Free space path loss
- Ray-tracing channel

- Winner II fading channel

- Loss due to gases, fog, clouds

R2021a: Up to 10 reflections
Array Beam Steering and RF Propagation

- Rectangular array of dipoles reflector-backed, operating at desire frequency
- (Electronically) Steer the array beam and assess coverage and links
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Hardware Deployment, Verification and Testing

Prototyping
SDR, FPGA, SoC

Simulink
HDL Coder
Wireless HDL Toolbox
HDL Verifier
Mission statement:

Provide high value reference applications and HDL IP blocks to accelerate the pace of design, implementation and verification of communication systems.

Applications:
1. 5G receiver reference applications
2. Custom OFDM reference applications
MIB Recovery Reference Application

- Decodes the Broadcast Channel (BCH), which contains the Master Information Block (MIB)
- Hardware-proven. Demo shipping in Comms Zynq HSP in R2020b
RF Pixels Verifies Millimeter Wave RF Electronics on a Zynq RFSoC Based Digital Baseband

Challenge
Test and demonstrate radio front-end designs that incorporate specialized RF electronics hardware and millimeter wave spectrum technology

Solution
Use MATLAB and Simulink to implement a digital baseband and deploy it to a Zynq RFSoC board for over-the-air testing

Results
- Engineering effort reduced by one year or more
- Digital baseband implementation completed by a single engineer
- Design iterations reduced from weeks to days

“By adapting the LTE golden reference model from Wireless HDL Toolbox and deploying it to a Zynq UltraScale+ RFSoC board using HDL Coder, we saved us at least a year of engineering effort—and this approach enabled me to complete the implementation myself, without having to hire an additional digital engineer.”
- Matthew Weiner, RF Pixels

Link to technical article
Over-the-air testing: Moving designs to the lab

Signal Generation and Transmission

RF Signal Generator

LAN/USB/GPIB

Signal Acquisition and Analysis

Spectrum Analyzer

LAN/USB/GPIB
Over-the-air testing: Moving designs to the lab

Signal Generation and Transmission

LAN/USB/GPIB
Zynq SDR

Signal Acquisition and Analysis

RTL-SDR
LAN/USB/GPIB
RF Instrument Connectivity in Wireless Waveform Generator App

Transmit wireless waveforms with RF instruments (e.g., Keysight/Agilent, Rohde & Schwarz)

- Need Instrument Control Toolbox
- Automatically discover available instruments
- Transmit/stop infinitely looped waveforms
- Configurable transmission frequency, output power and (integer) interpolation factor
MATLAB & Simulink Tools for Wireless Design

Physical Layer Design

Ubiquity
Ubiquitous Connectivity

Deployment & Verification

Efficiency
Efficient deployment & testing

System Engineering

Complexity
Design Complexity
How to Learn More

Wireless Communications product pages

mathworks.com/products/

5G

LTE

WLAN

Satellite-communications

Wireless communications solution page

mathworks.com/solutions/wireless-communications.html
Thank you