mmWave as a Key Enabler for 5G

5G North American Workshop
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Enabling Technologies : RAN & NW
Enabling Technologies - RAN (1/2)

Disruptive RAN Technologies for Significant Performance Enhancements

- Peak Data Rate
- Cell Edge Data Rate
- Cell Spectral Efficiency
- Mobility
- Cost Efficiency
- Simultaneous Connection
- Latency

**Technology for Above 6 GHz**

- Peak Data Rate Increase
  - Peak Rate 1 Gbps
  - New higher frequencies
  - Peak Rate 50 Gbps

**Post-OFDM**

- Spectral Efficiency & Cell Edge Enhancement
- Filter-Bank Multi-Carrier

**Advanced MIMO & BF**

- Cell Capacity Enhancement
- BF : Beamforming

Enabling Technologies - RAN (1/2)

Enabled RAN Technologies for Significant Performance Enhancements

- FSK QAM
- Half wavelength

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Enabling Technologies - RAN (2/2)

Disruptive RAN Technologies for Significant Performance Enhancements

Enhanced D2D
Areal Spectral Efficiency Increase

Advanced Small Cell
Capacity & Cell Edge Enhancement

Interference Management
Cell Edge Data Rate Enhancement

- Peak Data Rate
- Cell Edge Data Rate
- Cell Spectral Efficiency
- Mobility
- Cost Efficiency
- Simultaneous Connection
- Latency

D2D: Device-to-Device

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Enabling Technologies - Network

Innovative Network Technologies for Enhanced User Experience and Cost Reduction

- Flat Network
  - E2E Latency Reduction
  - Peak Data Rate
  - Cell Edge Data Rate
  - Cell Spectral Efficiency
  - Mobility

- Multi-RAT Interworking
  - Radio Capacity Enhancement
  - Energy & Cost Efficiency Increase
  - 4G eNB
  - 5G BS
  - Wi-Fi

- Mobile SDN
  - Central Controller
  - Simultaneous Connection
  - Cost Efficiency
  - Latency

*SDN: Software Defined Network*
Recent R&D Results Above 6GHz
Channel Measurements (1/2)

Three Types of Environments: In-Building, Campus, and Urban at 28GHz

**In-Building**
- Similar to Indoor Shopping-Mall
  - Five-story Building
  - Spacious Atrium Lobby
- Total 35 Rx Locations
  - Both for LoS and NLoS
  - Tx-Rx Distance: 10m ~ 55m

**Campus**
- Suburban Environments
  - KAIST Outdoor Campus
  - Tx Height 15 meters
  - Total 25 Rx Locations
  - Mainly for NLoS
  - Tx-Rx Distance: ~ 270m

**Urban**
- Urban Environments
  - Daejeon City
  - Tx Height 15 meters
  - 11 Rx Locations
  - Mainly for NLoS
  - Tx-Rx Distance: ~ 200m

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Pathloss (Urban)
- Currently 11 Rx Locations Available
  - All NLoS with 1 or 2 Reflections
  - Pathloss Exponent around 3
  - Shadowing Factor 6.3 dB

Clustering (Urban)
- K-Power-Means Algorithm
  - Based on Synthesized Omni Results
  - 10 Clusters are Good Compromise
  (3GPP SCM : 6, WINNER : 8~20)

Angle and Delay (Urban)
- Small Angle & Delay Spread
  - AoD : 5°, AoA : 25°
  - 90% RMS Delay : 55 ns

Large and Small Scale Channel Modeling to Produce SCM for High Frequency (28GHz)
mmWave Testbed - Overview

World’s First 5G mmWave Mobile Technology (May, 2013)
Adaptive array transceiver technology operating in mmWave frequency bands for outdoor cellular

<table>
<thead>
<tr>
<th>Base Station</th>
<th>Mobile Station</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Array Antenna</strong>&lt;br&gt;8x6 (≈48) Antenna Elements</td>
<td><strong>Array Antenna</strong>&lt;br&gt;4x1 (≈4) Antenna Elements</td>
</tr>
<tr>
<td><strong>RF + Array Antenna</strong></td>
<td><strong>RF + Array Antenna</strong></td>
</tr>
<tr>
<td><strong>UHD Streaming</strong></td>
<td><strong>Baseband Modem</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier Frequency</td>
<td>27.925 GHz</td>
<td></td>
</tr>
<tr>
<td>Bandwidth</td>
<td>800 MHz</td>
<td></td>
</tr>
<tr>
<td>Beamwidth (Half Power)</td>
<td>10°</td>
<td>20°(AZ) /140°(EL)</td>
</tr>
</tbody>
</table>

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**mmWave Testbed - Recent Updates**

World’s First 5G Data Transmission at Highway Speeds (Oct, 2014)
Record-breaking 1.2Gbps data transmission at over 100km/h, and 7.5Gbps in stationary conditions using 28GHz spectrum

5G Mobility Test
1.2Gbps @110km/h

Peak Data Rate
7.5Gbps


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mmWave Antenna/RFIC

28GHz Antenna and RFIC
360° Coverage and Polarization Interleaved Array and CMOS RFIC / FEM with One-Cable Connection Interface

28GHz Antenna

28GHz Array Antenna Module

160°

16 Chain

180°

Polarization Interleaved Array

Horizontal-Pol. Ant.

Vertical-Pol. Ant.

16 Chain

Antenna Gain

180°

28GHz RFIC

Beamforming CMOS RFIC / GaAs FEM

CMOS RFIC

GaAs FEM

One-Cable Connection

Measured Low Phase Noise

Phase Noise

-103 dBC/Hz

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**mmWave Antenna/RFIC**

**60GHz Antenna and RFIC Based on IEEE 802.11ad**

360° Coverage antenna and 16-chain beamforming CMOS RFIC (Tx/Rx EVM -25 dB)

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**60GHz Antenna**

- **60GHz Module with Array Antenna**
  - End-Fire Antenna
  - Dual-Pol. Antenna
  - Module size: 9.0 X 7.9 mm²
  - 360° Coverage
  - Polarization Loss < 3 dB
  - D2D Active Measurement System
  - Embedded BB

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**60GHz RFIC**

- **Beamforming CMOS RFIC**
  - EVM -25 dB
  - 16-chain Beamforming
  - Measured Low Phase Noise
  - Phase Noise -99 dBC/Hz

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Thank You
References


